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FIG CHARACTERISTICS USEFUL IN THE IDENTIFICATION OF VARIETIES^{1,2}

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INTRODUCTION

CULTURE OF THE FIG, *Ficus Carica* L., began many centuries ago somewhere in Eurasia. Primitive man recognized the delectable qualities of the fruit, selected seedling trees bearing superior kinds, and thus established definite fig clones or varieties. Egyptian hieroglyphics and other pictographs give us some idea of the high regard in which the fig was held, but the Greeks have given us what is probably the earliest written indication of fig taxonomy. In the *Odyssey*, Ulysses says to his father: "Through these very trees we were going and thou didst tell me the names of each of them. Pear trees thirteen thou gavest me, and ten apple trees, and figs two score" (Homerus, 1909).⁴ In the third century B.C., varieties of fruits were not only named but studied. Theophrastus (1916) says: "Most of the wild kinds [plants] have no names and few know about them, while most of the cultivated kinds have received names and they are more commonly observed; I mean such plants as vine, fig, pomegranate, apple, pear, bay, myrtle, and so forth; for, as many people make use of them, they are led also to study the differences."

During the centuries in which the fig has been cultivated, varieties have so greatly multiplied that the present number is not even approximately known. In the first century of the present era, Pliny (Plinius Secundus, 1855-90) listed 29 varieties of figs, and Columella (1745) mentioned 8 varieties under locality names. La Quintinie (1692) described 9 varieties of French figs, mostly in terms of color, as, for example, "the

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⁴ See "Literature Cited" at the end of the paper for complete data on citations, which are referred to in the text by author and date of publication.

great yellow fig." Noisette (1829) described 37 kinds grown in France. Descriptions and synonymies of 68 figs found in England were given by Hogg (1866). Barron (1891) described 66 varieties being grown in hothouses of the Royal Horticultural Society, Chiswick, England. The varieties in the Chiswick collection were obtained by the United States Department of Agriculture in 1894 and established in California, first at Niles, later at Chico, then at Fresno, and finally at Riverside.

Vallese (1909) describes 9 varieties of caprifigs and 38 varieties of edible figs found in Italy; he also lists, without descriptions, the names of 94 other Italian varieties. Probably the most comprehensive treatment of fig varieties is that of Eisen (1901), who lists or describes 406 varieties, although some of the names are undoubtedly synonymous. Among others who have contributed original descriptions of fig varieties may be mentioned Starnes and Monroe (1907), describing 118 varieties grown in the state of Georgia; Estelrich (1910), 50 varieties grown in the Balearic Islands; Bobone (1932), 27 varieties found in Portugal; and Mauri (1939*a, b*), 16 varieties of caprifigs and 19 of edible figs cultivated in Kabylia. There are now 162 distinct varieties of caprifigs and edible figs in the collection of the University of California at Riverside.

The dearth of adequate descriptions of fig varieties has long been recognized. Lindley (1831), for example, wrote:

I have searched for authorities and descriptions to enable me to point out those differences which should distinguish one sort from another, but I have not succeeded in satisfying myself. I have indeed found names in books on gardening accompanied by what the writers might have considered as descriptions; but several of them have been so defective as to give the reader but little chance of applying them to the fruit they were intended to designate.

Eisen (1901) also pointed out that figs had been insufficiently described and that both authors and nurserymen copied the available descriptions without giving them critical research and comparison. The descriptions by Eisen himself leave much to be desired, and Waugh (1908), with Eisen's work available, wrote regarding figs: "Along with defective descriptions goes an almost entire lack of classification."

CLASSIFICATION

A previous publication (Condit, 1933) presents a section on the botany and classification of figs, which may be summarized as follows. The fig fruit is a hollow receptacle or syconium, on the inner surface of which the flowers are produced. Fundamentally, the flowers are of two kinds, staminate and pistillate. Staminate flowers are found only in receptacles bearing short-styled flowers. Pistillate flowers are found in

all figs and may be either short-styled or long-styled. Figs having short-styled flowers belong to the most primitive horticultural group, the caprifigs. All figs having long-styled flowers develop under favorable conditions into edible fruits and are classified, horticulturally, into three groups: Smyrna, San Pedro, and common.

Caprifig Type.—The caprifig is the primitive type of cultivated fig, the other three types having undoubtedly evolved from it. The short-styled flowers or gall flowers of caprifigs are adapted to oviposition by an insect, the fig wasp (*Blastophaga psenes* L.); and receptacles of the three crops of the caprifig tree harbor the larvae, pupae, or, temporarily, the adults of this insect. The three crops of the caprifig are the profichi (April to June), the mammoni (June to November), and the mamme (November to April).

Stanford and Roeding No. 3 are two standard varieties of caprifigs in California. Croisie (Cordelia) is a caprifig which is completely parthenocarpic in the profichi crop, the fruit becoming pulpy and edible rather than remaining dry and pithy as do most caprifigs.

A type of fig was described by Pontedera (1720) as "Erinosyce." According to Eisen (1896), profichi of this type contain male flowers as well as gall flowers with wasps, and mammoni figs contain "perfect female flowers" and gall flowers with wasps. Now, however, it is recognized that all pistillate fig flowers are potentially fertile, and there is no valid distinction between "perfect female flowers" and gall flowers in mammoni figs. If not used for oviposition by the blastophaga, any of these flowers may become pollinated and fecundated. Apparently, therefore, Erinosyce is a caprifig with normal profichi and with mammoni which have fertile seeds.

Smyrna Type.—Figs of Smyrna type mature only after the pollination of their long-styled flowers and the resultant development of fertile seeds. Without such stimuli, immature figs both of the breba crop (first crop) and of the main crop usually shrivel and drop when about an inch in diameter. Sometimes a few brebas develop without this stimulus. The commercial fig industry of Asia Minor, that of Greece, Algeria, Portugal, and to a considerable extent that of California, are based upon this type of fig. Calimyrna or Lob Injir, Kassaba, and Bardajik are varieties of this type.

Common Type.—Figs of common type are parthenocarpic; that is, they do not require the stimulus of caprification and seed development in order to have the fruit mature. Commercial varieties such as Trojano and Dottato of Italy, Fraga and Lepe of Spain, Adriatic and Mission of California are of common type.

San Pedro Type.—Figs of San Pedro type combine the characteris-

ties of both Smyrna and common type: brebas develop without the stimulus of flower pollination and fecundation; second-crop figs are of Smyrna type and drop unless they are caprifiged. In California, varieties of this type, such as San Pedro, Dauphine (grown near Indio), and Gentile, are of little or no commercial importance. According to Bobone (1932), several varieties of this type are produced in Portugal. Dauphine is grown commercially in the vicinity of Tokyo, Japan.

Botanical Classification.—*Ficus Carica* was described by Linnaeus (1753) as follows:

Ficus carica.

Ficus foliis palmatis. Hort. cliff. 471. Hort. ups. 305. Mat. med. 478. Amoen. Acad. 1. p. 24. Roy. Lugdb. 211.

Ficus communis. Bauh. pin. 457.

Ficus. Dod. pempt. 812.

♂ *Caprificus.* Bauh. hist. 1. p. 134.

β *Ficus humilis.* Bauh. pin. 457.

Habitat in Europa, australi, Asia.

Bauhin (1623) had already used the terminology *Ficus communis* and *F. humilis*. Since the time of Linnaeus, various botanists have suggested other terminologies for certain types. For example, Galesio (1817–20) recognized the following types among the caprifigs: *Fico selvaggio*, the normal caprifig; *Fico della natura*, a caprifig with only one crop a year; *Fico mostro*, a caprifig which matures no perfect fruit, only polliniferous figs; *Fico mula*, a fig which becomes pomologically but not botanically ripe; *Fico semi-mula*, a fig which, when pollinated, becomes both botanically and pomologically mature.

Gasparrini (1845) expressed the opinion that the caprifig was not the male form of the fig but a species so different that it could well be taken as the type of a distinct genus. Few if any botanists, however, accepted this opinion, and Solms-Laubach (1882) showed that the edible fig and the caprifig are forms of one species, *Ficus Carica*.

Eisen (1896) stated that his studies and experiments were concerned principally with four classes of figs: Caprifigs, *Ficus Carica silvestris*; Smyrna figs, *Ficus Carica smirniaca*; Common figs, *Ficus Carica hortensis*; and San Pedro figs, *Ficus Carica intermedia*. He designated the Cordelia type of fig as *Ficus Carica relict*a and (Eisen, 1901) listed a large number of Italian and French figs with a Latin terminology, as *Fico dorato*, *Ficus lutea*, and so forth.

Celi (1907) proposed the following nomenclature: *Ficus Carica sylvatica*, nonedible caprifigs; *Ficus Carica sub-sativa*, reverted figs with fruit slightly or not at all edible; and *Ficus Carica sativa*, common edible figs with fertile seed (slightly improved kinds) or sterile seed (more highly improved kinds).

Later, Tschirch (1911) proposed the following classification: *Picus Carica crinosyce*, the wild fig; *Picus Carica alpha caprificus*, the capri-fig; and *Picus Carica beta domestica*, the cultivated edible fig. However, according to Silvestri,² this classification of *Picus Carica*, which was also published by Ravasini (1911) is incorrect.

Pomological Classification.—The classification of figs into types, as outlined in the preceding section of this paper, is based mainly on botanical characters and is, therefore, fairly definite. Pomological classification of fig varieties, however, is not so simple. This is true of other fruits, such as apples, of which Beach *et al.* (1905, p. 23) wrote: "In fact they vary so greatly that they almost defy any attempt to classify them into groups." And yet various authors have found that the grouping of fig varieties according to certain characters aids considerably in their identification.

Noisette (1829) classified figs into two groups based on external color: (1) yellow or green figs and (2) reddish, violet, or brown figs. Each of these two groups he subdivided into fruits spherical or oblate, and fruits oblong.

Hogg (1866) based his classification (1) upon shape—fruit round, roundish, or turbinate, and fruit long, pyriform, or obovate; (2) upon color of skin—skin decidedly dark and skin pale or tinged with brown; and (3) upon color of flesh—flesh red and flesh white or opaline.

Celi's (1907) classification was based (1) upon shape—ovoid, spherical, or oblate; (2) upon the fruit peduncle—short or long; and (3) upon external color. Vallese (1909) grouped varieties into two sections: those maturing early and those maturing late; and under each section he made two classes: white fruits and dark-colored fruits. Estelrich (1910) simply grouped Mallorcan figs into six classes: top-shaped, egg-shaped, pyriform, conical, spherical, and oblate.

Bobone (1932) is apparently the only author who differentiates between brebas and second-crop figs in a pomological key. He further subdivides figs on the basis of external color, shape of the base, shape of the body, and color of the pulp.

Variety studies over a period of twenty years have convinced me that the construction of artificial keys is of decided value in the identification of fig varieties; that such keys serve to bring out and emphasize minor fruit characters which would otherwise be overlooked; and that it is impossible for any key to be infallible, since the fig, like most other fruits, is markedly affected by environmental conditions. For personal use I have constructed keys of both profichi- and mamme-crop caprifigs and of both breba- and second-crop edible figs. These keys are based on

² Silvestri, F. In letter to author from Portici, Italy, March 28, 1929.

the following fruit characters: external color, form, size, neck, fruit stalk or peduncle, ribs, eye and eye scales, skin, bloom, surface markings such as hairs and white flecks, color of meat and pulp, and seeds.

Latex is a character common to all trees of the genus *Ficus*, including *F. Carica*. Characters which show little if any variety differences are: wood, roots, bark (some exceptions noted later in the section, "Bark," p. 52), burrknots, and bark tubers. The following characters do, however, have significance in variety descriptions: leaves, habit of tree growth or branching, buds, crops, fruitfulness, and season.

THE FRUIT

Pomologically speaking, the fruit of the fig is a "syconium," a name originally suggested by Mirbel (1813):

2e Genre. Sycône, Syconus.

Clinanthe très-dilaté, de forme et de consistance variables, portant des fruits carcérulaires ou des drupéoles (figs, ambora, dorstenia).

"Syconium" may be further defined as a collective fleshy fruit, in which the ovaries are borne upon an enlarged, more or less succulent, concave or hollow receptacle. Botanically, the fruits of the fig are the one-seeded ovaries which line the inner wall of the receptacle. According to Smith *et al.* (1928, p. 451), "The fig resembles a multiple fruit in including many individual fruits, each developed from a single flower. It differs in the fact that the individual fruits are not adherent." The fig is unique among fruits in having an apical orifice or ostiole which connects the cavity of the receptacle with the exterior.

Syconia of *Ficus Carica* are borne in the axils of leaves. Those produced late in the season generally persist throughout the winter as dormant fruit buds and push out with, or sometimes slightly in advance of, the leaves. Brebas or first-crop figs are therefore produced on wood of the previous season. Syconia of the main crop are usually single or solitary, but in some varieties are borne in pairs (fig. 1), one on each side of the vegetative bud.

Color of Figs.—There are three general color classes into which fresh figs may be segregated as shown in plate 1: (1) fruit green or yellow; (2) fruit more or less shaded with bronze, copper, or violet; and (3) fruit decidedly dark, violet, or purplish black. The limits of these color classes are not always sharply defined, the external color depending upon the light intensity, temperature, humidity, and upon the presence or absence of fertile seeds. Thus the Kadota fig in a cool coastal climate is green in color, while in the hot inland climate it is a bright lemon yellow. Adriatic, as Eisen (1901) states, is green or bluish green in color

in the cool climate of San Francisco Bay, while in the hot inland valleys it is often golden yellow. In some Calimyrna orchards there are two color classes of fruit: most trees bear fruit typically golden yellow in color; but for reasons not yet explained, some trees bear figs light lemon

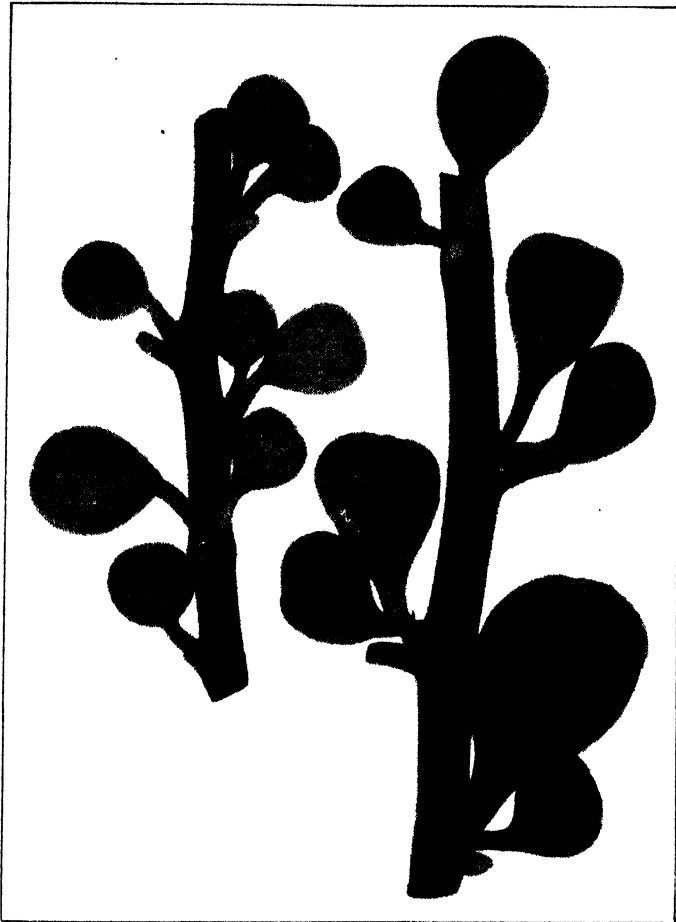


Fig. 1.—The Kadota (left) and the Turkey (right), as well as many other varieties of figs, produce two syconia in the axil of a single leaf. ($\times 0.6$.)

yellow in color and still more attractive in appearance than the golden-yellow fruit typical of the variety. The Stanford Smyrna fig remains green or yellowish green until mature and then fades to a straw color as the fruit dries.

Examples of bronze or copper-colored figs are (plate 1): Brunswick, Celeste, Gouraud Rouge, Pied de Boeuf. Figs shaded with violet are St.

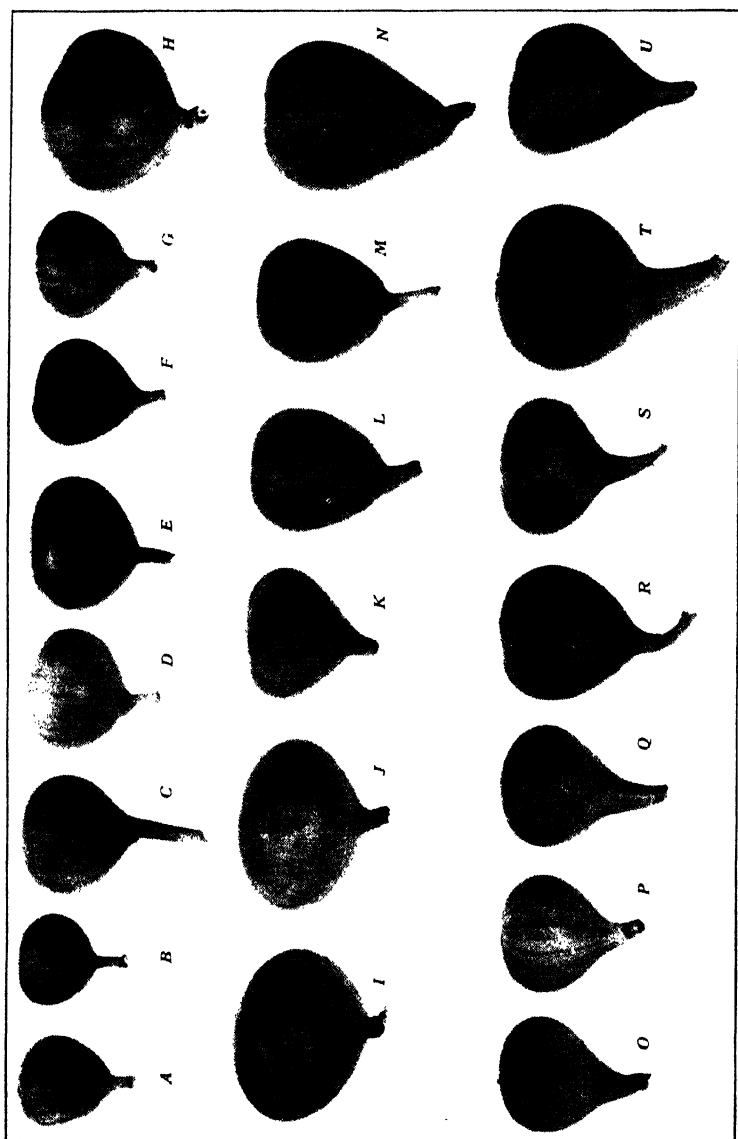


Fig. 2.—Forms of fig fruits: A-E, spherical without neck; F-H, spherical with neck; I, oblate without neck; J, oblate with neck; K-M, turbinate; N, pyriform, with neck undifferentiated from body; O-T, pyriform; U, oblique-pyriform. 4, Precoce de Barcelone; B, Ischia; C, Pastilliere; D, Madeleine; E, Marseilles; F, Toulousienne; G, Martinique; H, Dauphine; I, San Pedro; J, Calimyrna; K, Bourjasotte Grisee; L, Brunswick; M, Gouraud Rouge; N, San Pietro; O, Fraga; P, Fanaché; Q, Gota de Mel; R, Pied de Boeuf; S, *Ficus palmata*; T, Marabout; U, Datte. ($\times 0.35$.)

Jean Grise and Partridge Eye. Seldom are these intermediate figs so attractive in color for the fresh-fruit market as the clear yellow or the purplish-black figs. Mission, Turkey, Ischia Black, and Pastiliere are deep purplish black in color (plate 1). The black color persists in the dried fruit of the Mission and Ischia Black, but changes to an undesirable brown color in the Turkey. The late George Roeding (1917) wrote: "If there is any serious objection to the black [Mission] fig, there is only one and that is, it is black."

Black color is objectionable in the dried fruit since black figs do not compete well in the market with light-colored California or imported figs and they are generally unmarketable for use in bakery products. Bleaching with hydrogen peroxide removes most of the black color, but the fruit is apparently not able to compete successfully with dried figs of lighter shades.

Color chimeras or sports in figs have been described by Collins (1919) and by Condit (1928). Such a fig is Panaché (plate 1, *B*), a French fig beautifully marked with green and yellow stripes and seen occasionally in California. Twigs bearing Kadota, Calimyrna, or Adriatic figs with purplish-black sectors or with variegated leaves are sometimes found. These should be marked for further observation and possible propagation.

Color of fresh figs, like that of other fruits, is often obscured or modified by the bloom, which is a surface skin character. Furthermore, color is seldom uniform over the whole surface. Purplish-black Barnissotte commonly shows irregular patches of green persisting around the apex or on the sides of the body. Dark-colored Constantine and Bourjassotte Grise usually show a broad circle of green around the eye of mature fruits. Grasovsky and Weitz (1932) state that Shumnari "is very easily distinguished by a bright red circle around the eye," the skin being green with brownish ribs and the eye scales bright red. It is well, therefore, to note color of neck, apex, scales of eye, shaded side, and so forth, if these are colored differently from the body of the fruit. Most figs are green until practically full size and then gradually assume the mature color characteristic of the variety. A few figs, notably *Violette de Bordeaux* and *Ischia Black*, show a distinct reddish-brown color before they are half grown. In some cases the skin color is modified by colored meat. Thus green *Monstreuse* (described by Eisen, 1901, p. 255) and caprifigged *Adriatic* often have a violet shade due to the underlying violet meat. Miller (1768) says of *Ischia Green* that "the skin is thin, of a green color, but when it is fully ripe, it is stained through by the pulp to a brownish cast."

Form.—The form of the fig fruit, like the color, is affected by cli-

matic conditions, by the presence or absence of fertile seeds, and, to some extent, by vigor of growth. Although there is considerable variation in fruit on the same tree and during the same season, forms of fresh figs are fairly characteristic of the variety. Form is commonly associated with the presence or absence of a neck.

Bobone (1932) uses three measurements in determining the form of the fruit: C , length; D , diameter; and A , the distance between the base and the point of greatest diameter. The shape of the fruit is then expressed by the ratios D/C , $D/2A$, or A/C . When D/C is greater than 1.1, the fruit is said to be oblate; when between 0.9 and 1.1, round; and when less than 0.9, oblong. Or when $D/2A$ is greater than 1.0, the fruit is said to be oblate; when between 0.7 and 1.0, round; and when less than 0.7, oblong.

Forms of fig fruits illustrated in figure 2 and specified in the following outline are typical of varieties found in the variety orchard of the Citrus Experiment Station at Riverside.

Spherical:

Without neck—Precoce de Barcelone (fig. 2, A), Ischia (fig. 2, B), Pastiliere (fig. 2, C), Madeleine (fig. 2, D), and Marseilles (fig. 2, E)

With neck—Toulousienne (fig. 2, F), Martinique (fig. 2, G), and Dauphine (fig. 2, H)

Oblate:

Without neck—San Pedro (fig. 2, I)

With neck—Calimyrna (fig. 2, J)

Turbinate—Bourjassotte Grise (fig. 2, K), Brunswick (fig. 2, L), and Gouraud Rouge (fig. 2, M)

Pyriform:

Neck undifferentiated from body—San Pietro (fig. 2, N)

Neck prominent:

Thick and short—Fraga (fig. 2, O), Panaché (fig. 2, P), Pied de Boeuf (fig. 2, X)

Elongated, often curved—Gota de Mel (fig. 2, Q), *Ficus palmata* (fig. 2, S), and Marabout (fig. 2, T)

Oblique-pyriform—Datte (fig. 2, U)

Form of fresh fruit is of importance both in canning and in fresh-fruit shipping. It is partly on account of their compact spherical or oblong shape (without a prominent neck) that Brunswick and Kadota are excellent varieties for canning. Calimyrna, oblate in form, with short neck (fig. 2, J), is ideal in form for packing in the egg-cell fillers (fig. 3) widely used for long-distance shipments. Pyriform figs, like Mission, are commonly wrapped in tissue and packed on their sides in one-layer baskets.

Size.—Figs are, in general, large, medium, or small. For fresh fruit, average diameter of the body gives a good indication of size. Arbitrary

limits can be established for each size grade, as shown in table 1. On account of the very diverse forms found in figs, a more accurate size classification would be one which considered weight as well as diameter, as suggested by Bioletti (1938) for grapes.

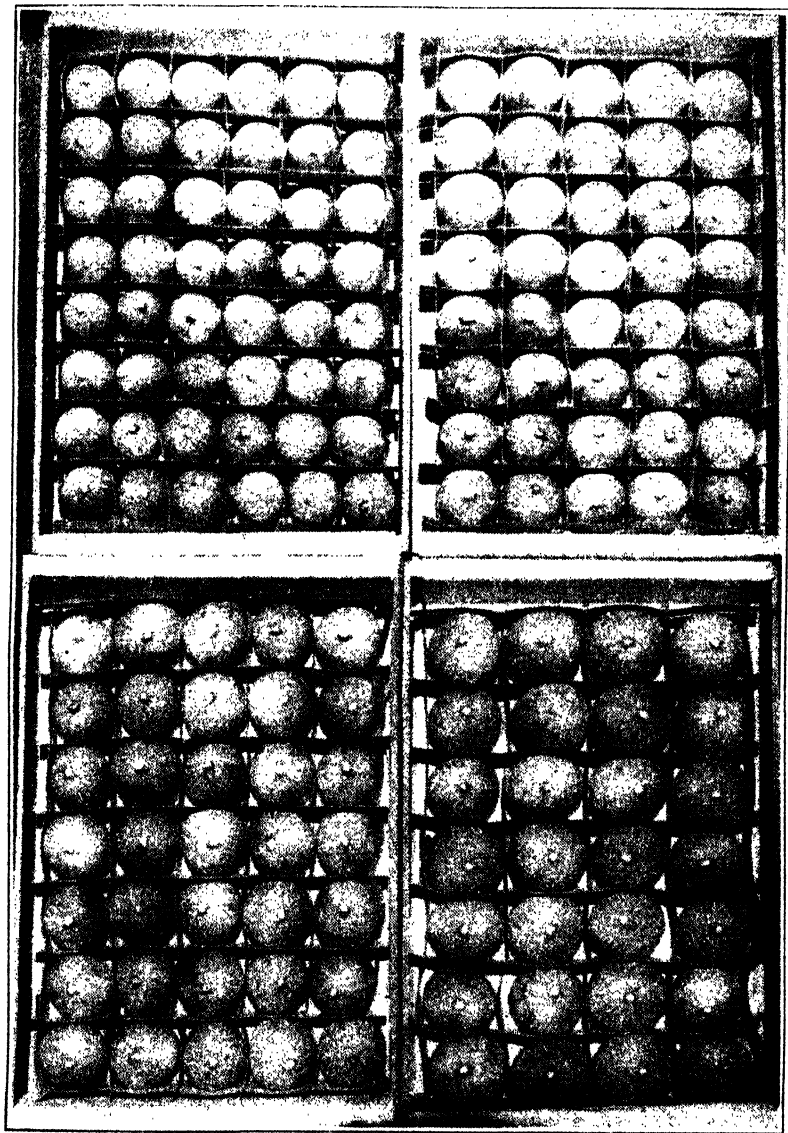


Fig. 3.—Calimyrna figs packed in egg-cell fillers in standard boxes for long-distance shipment: upper left, 6×8 ; upper right, 5×8 ; lower left, 5×7 ; lower right, 4×7 .

In their descriptions of fig varieties, Starnes and Monroe (1907) give measurements of (1) perpendicular and (2) transverse axes of fruits. The limits of these measurements for figs of the various sizes are: small, 29-46×28-38 mm; medium, 38-54×35-49 mm; large, 52-70×41-56 mm; very large, 75×66 mm.

Van Velzer (1909) states that the "smallest figs measure less than an inch in each dimension" and gives as an illustration, Lipari, "the smallest of all edible figs." He adds that "the largest sometimes grow 5 inches long with an equal width" and illustrates with Black Portugal as the

TABLE 1
SIZE GRADES OF FRESH FIGS BY BODY DIAMETER

Class	Size limits, millimeters	Variety example
Very small	<25	Celeste
Small	25-32	Ischia
Below medium	33-38	Ischia Black
Medium	39-48	Mission and Brunswick
Above medium	49-54	Oshorn
Large	55-60	Calimyrna
Very large	>60	Turkey

largest fig grown. Grasovsky and Weitz (1932) describe Khidari as a large fig measuring about 65×60 mm or 70×65 mm. Eisen (1901) refers to Lipari as "the smallest of all figs of the *Ficus Carica* species—about three fourths inch to 1 inch long."

Size grades for figs shown in table 1 are satisfactory for most purposes, although they are approximate only. Size grades for certain varieties are sometimes designated. For example, in packing fresh Calimyrna figs for shipment in egg-cell fillers (fig. 3), the California Fruit Exchange (Anonymous, 1938, p. 26) specifies that the figs "shall conform to the following sizes and shall be so marked: 28, 35, 40, 48, 54, 60, and 72. It is recommended that no sizes smaller than 48 be packed except Kadotas, and in this variety no sizes smaller than 60 be packed." The size of the standard fig box used by the Exchange is 7×16⁷/₁₆ inches, inside measurement. Fillers for Calimyrna figs (fig. 3) have compartments as follows:

Number	Size, inches	Fig diameter, inches	Fig diameter, millimeters
28 (4×7)	35/16×39/16	38/16	60
35 (5×7)	32/16×34/16	34/16	55
40 (5×8)	30/16×32/16	32/16	51
48 (6×8)	26/16×30/16	30/16	48

In contracts with growers, some canners specify that Kadota figs shall

be not less than 1 inch and not over $1\frac{3}{4}$ inches in diameter. Figs for canning are run through a sizer and packed in various containers. The California Packing Corporation reports^a the following counts in a no. 10 can, based on a fill of 81 ounces of fruit: fruit size $2\frac{1}{16}$ inches, 117; size $2\frac{5}{16}$ inches, 67; size $2\frac{7}{16}$ inches, 55; and fruit size $3\frac{0}{16}$ inches, 38.

Figs on the same tree may vary in size—markedly so in some varieties. Size is affected by climate, vigor or health of tree, size of crop, cultural conditions such as pruning or irrigation, and by the character of the seeds. In cool coastal climates, such figs as Adriatic and Osborn reach an unusually large size—at least twice the volume of figs of the same variety grown in the hot valleys of the interior. The largest Turkey figs are grown on heavily pruned and copiously irrigated trees in cool climates near the coast. As pointed out later in this paper (see section, "Effects of Caprification," p. 32), Kadota figs having fertile seeds are considerably larger than those of the same variety having sterile seeds.

Caprifigs of the profichi crop are similar in size to edible figs. Mamme caprifigs, however, range much smaller in size than profichi, seldom reaching 48 mm in diameter.

Neck.—The neck is that part of the body of some figs located next to the stalk. There are figs, such as Marseilles (fig. 2, *E*), that have no neck. Others, such as San Pietro (fig. 2, *N*) and Brunswick (fig. 2, *L*), have the basal half narrowing so gradually between the body and stalk that they also can generally be described as without neck.

In some figs the neck is thick and joins the body abruptly, as in Calimyrna (fig. 2, *J*); in others, such as Col de Dame, it is thick but tapers more gradually from stalk to body. The neck may be long and slender, as in Marabout (fig. 2, *T*); if so, it is often curved or somewhat falcate.

In most figs the neck is round in cross section; in a few it is angular or triangular. The neck of some figs is characteristically compressed or flattened laterally, as in Calimyrna and many of its seedlings, such as Maslin caprifigs No. 147 and No. 148. Some common figs also have a flattened neck, examples being Bourjassotte and Martinique.

Stalk.—The stalk joins the fig body or neck to the twig. It may be short, medium, or long, thick or slender, straight or curved, and rounded or angular in cross section. The stalks of some figs, such as Violette de Bordeaux (fig. 4, *E*), Yellow Neches (fig. 4, *B*), and many specimens of Brunswick (fig. 4, *A*), are prominently swollen or enlarged, especially near the body.

The stalk is generally firmly attached to the twig; it loosens naturally after an absciss layer is formed and allows partly dried figs to drop.

^a Dodd, H. In letter to author from San Francisco, California, September 11, 1939.

Figs intended primarily for drying are seldom picked from the tree in California, although the practice is common in some Mediterranean districts, especially those near the seacoast. Pickers of fresh Calimyrna figs commonly give the fruit a twist which breaks the neck loose and leaves the stalk on the tree. On the other hand, Turkey figs grown near Los Angeles are picked and marketed with the stalk attached to the

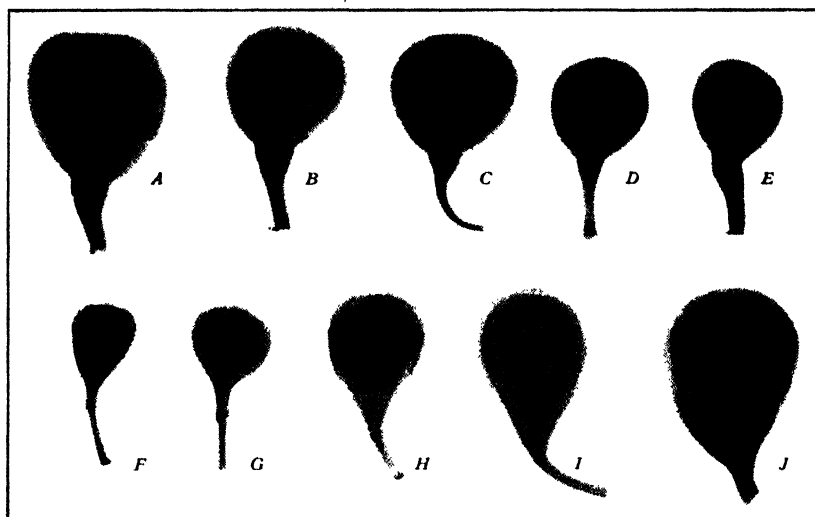


Fig. 4.—Fruit stalks: A–E, variously enlarged; F–I, long and slender; J, short and thick. A, Brunswick; B, Yellow Neches; C, Monaco Bianco; D, Precoce de Barcelone; E, Violette de Bordeaux; F, *Pseudo-Carica capri*; G, *Palmata capri*; H, Celeste; I, Hunt; J, Mission. ($\times 0.75$.)

fruit. In a few figs, notably Pastiliere and Barnissotte, the stalk is rather loosely attached and permits many mature fruits to drop before drying starts.

At the apex of the stalk next to the body are three more or less prominent bracts. These are generally closely appressed to the body but are sometimes loose and flaring. They may be large, medium, or small, green or colored the same as the body, triangular or rounded, and uniform or scarious-margined.

Ribs of the Fruit.—The ribs of the fig fruit are longitudinal ridges running from base to apex (Eisen, 1901). The surface of some figs, like that of second-crop Kadotas, is smooth and almost entirely devoid of ribs. At the other extreme are Pied de Boeuf and Castellana, the ribs of which are so prominent as to make the surface corrugated.

Ribs are mostly confined to the body of a fig, seldom being prominent on the neck or at the apex. They may be continuous and unbranched or

may dissolve toward the apex into branches. Sometimes, especially in immature fruit, they show as mere lines colored more darkly than the body. Ribs are narrow and well elevated in Marseilles and Martinique, while in the Turkey fig they are broad and only slightly elevated. The presence of prominent well-elevated ribs is a detriment for fresh-fruit shipping, because the skin is thus more subject to injury in handling.

Ostiole and Eye.—"Ostiole" or *ostiolum* means literally "little door." In many fungi and lichens, the mouth or terminal pore of the perithecium is called the ostiole. According to Gwynne-Vaughan and Barnes (1927, p. 130) the ascocarp "may assume a flask-shaped outline, opening by a terminal pore, the ostiole." Gaumann and Dodge (1928, p. 134) state that at the top of some perithecia "there is formed . . . a special opening (ostiole) whose canal is often closely covered with hyphal ends." In mycology, the term "ostiole" clearly refers to the whole structure, both entrance, or eye, and canal, and not to the eye alone.

The apical opening characteristic of the receptacles of fig species is also commonly called ostiole. For example, Cunningham (1888, p. 15) wrote of receptacles of *Ficus Roxburghii* that "the ostiole is at this time closed by a firm, solid plug of closely appressed ostiolar bracts." Hutchinson and Dalziel (1927-37) use the ostiole (mouth) of the receptacle as one of the main characters for separating species of *Ficus* into subgenera.

Eisen (1901) refers to this structure as the "eye" and states that it is "the opening in the broad end or apex of the fig." He adds that "Some writers refer to the eye as the 'mouth' of the fig or 'ostiolum.'" Brown and Walsingham (1917) in their account of *Ficus Sycomorus* in Egypt, note that the female fig wasp makes her way through the "eye" of the fig to the open air. Corner (1933) uses the term "orifice" in his revision of the Malayan species of *Ficus*. The eye is sometimes referred to as the "umbilicus." Roxburgh (1832, p. 529) states that in *Ficus hirsuta* the "umbilicus [is] scaly and scarcely elevated above the surface of the fruit." King (1887-88, p. 1) also used this term in describing the structure of fig fruits: "receptacles closed at the mouth by numerous scales arranged in rows, the uppermost of which often partly project externally and form an umbilicus."

In view of the foregoing statements, it seems best to differentiate between the ostiole or complete orifice of the syconium and the eye or umbilicus, the part which is apparent at the surface. The eye of the immature syconium of *Ficus Carica* appears to be completely closed by the scales or ostiolar bracts. The female blastophaga, however, is able to push her way between the scales, as previously described (Condit, 1918a). Hansen (1929) found that thrips enter freely. As figs mature,

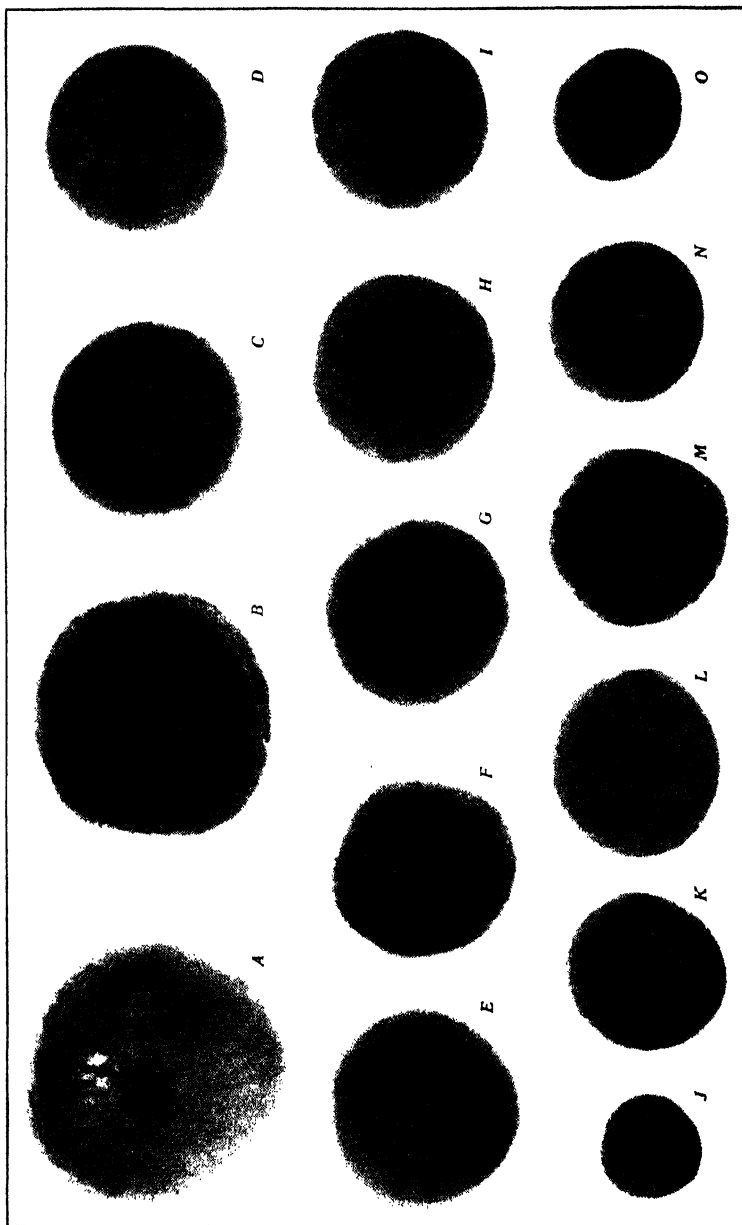


Fig. 5.—Fig varieties showing types of eyes: *A*, Calimyrna; *B*, Turkey; *C*, Fraga; *D*, Panaché; *E*, Brunswick; *F*, Osborn; *G*, Madeline; *H*, Mission; *I*, Castellana; *J*, Palmata capri; *K*, Martinique; *L*, Constantine; *M*, Barnissotte; *N*, Partridge Eye; *O*, Celeste. *A* and *B* are large; *C*-*M*, medium, and more or less open; *H*, *I*, *N*, *O*, small; and *J* has a craterlike protuberance. ($\times 0.1$.)

the eye may remain fairly well closed, sufficiently so in Mission (fig. 5, *H*) and Kadota to prevent *Carpophilus* beetles from entering, as pointed out by Smith and Hansen (1927). Eisen (1901, p. 179) concludes that "there is no doubt that the principal function of the eye of the fig is to keep out bacteria and insects, and the closed form of the fig receptacle is undoubtedly effected by nature in order to prevent parasites from spoiling the sugary juice of the fig."

Hansen and Davey (1932), investigating the transmission of smut and mold in figs, found that

While the fig is very young, up to about the size of a large hazelnut, the eye scales are quite pliable, but, as it develops further, the scales become hard and rigid and are able to offer considerable resistance to any insect trying to enter the fruit. Later, as the fruit matures, the eye scales again loosen and spread apart until at full maturity there may be a clear passage to the interior of the fig from 2 to 5 mm in diameter.

According to Smith and Hansen (1931), the diameter of the ostiolar opening varies from 2 to 10 mm in the different varieties. Celeste (fig. 5, *O*) is an example of a fig with a small, well-closed eye. Figs with medium eyes, sufficiently open, however, to allow beetles to enter, are Brunswick (fig. 5, *E*) and Adriatic.

Stansel and Wyche (1932, p. 23, fig. 11) report that "the fruit of the Magnolia variety remains upright and has a more open end than that of the other varieties, which probably accounts for its tendency to sour readily, especially during damp weather." Potts (1917) also refers to the open eye of Magnolia which may be entered and injured by insects. Calimyrna and Turkey figs have large, open eyes (fig. 5, *A* and *B*) allowing easy penetration of beetles and even larger insects, such as honeybees (fig. 6). Actual diameter measurements of body of fruit and of ostiolar opening of different fig varieties are given in table 2 for comparison.

As mentioned by Hansen and Davey (1932), there may, at maturity, be a clear passage to the interior of the fig. This is especially true of uncaprified figs and of those having a hollow center, such as Turkey, Madeleine, Datte, and Brunswick. On the other hand, as is often the case in Kadota, Turkey, Calimyrna, and especially in caprified figs having a solid pulp, the eye may be wide open but the ostiole closed at the base by scales or turgid flowers.

In some caprified figs the eye is in the center of a broad depression; in others, the eye protrudes from the rounded or flattened apex like an umbilicus. The eye of Maslin 150 and of *Ficus palmata* caprified (Pal-mata capri, fig. 5, *J*) is surrounded by a prominent craterlike protrusion.

Some figs, such as Kadota and Calimyrna, exude at maturity a clear,

sparkling, topaz-colored drop of gum into the ostiole and eye and are, therefore, "self-sealed." A seedling Smyrna-type fig from the Maslin orchard at Loomis, California, was selected as a "self-sealing" fig and

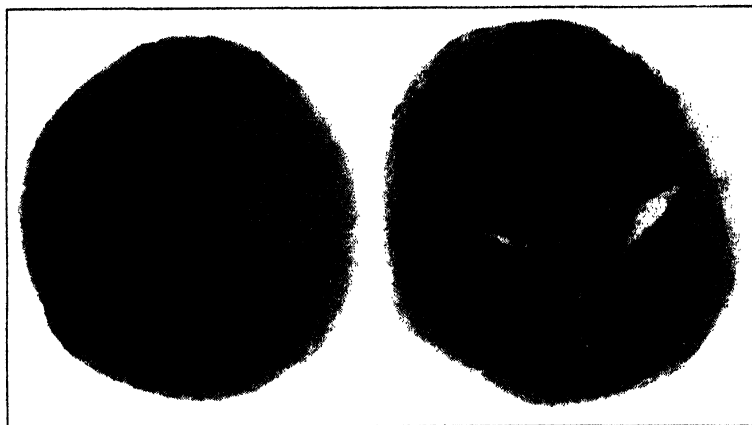


Fig. 6.—Calimyrna figs showing (left) the body of a honeybee in the eye of the fruit and (right) a triangular split common in this variety.

named "Rixford" by W. T. Swingle. He reported (Swingle, 1909) that the self-sealed figs "show a drop of pellucid gum completely filling the very narrow mouth of the fruit when it matures. . . . The drop of hard-

TABLE 2
COMPARATIVE DIAMETERS OF BODY OF FRUIT AND OSTIOLAR
OPENING OF DIFFERENT FIG VARIETIES*

Variety	Range of body diameter	Range of ostiolar-opening diameter
	<i>mm</i>	<i>mm</i>
Adriatic.....	33-45	2.5- 4.5
Calimyrna.....	54-68	6.0-12.0
Kadota.....	33-44	3.0- 8.0
Mission.....	35-48	2.0- 5.0
Turkey.....	43-56	4.0- 9.0

* Measurements were made on ten figs of each variety, selected at random on the tree.

ened gum that closes the mouth is usually from one-sixteenth to one-eighth inch in diameter, sometimes concealed just within the mouth, but usually protruding outside." The variety is not consistent in its self-sealing behavior, however, and has not succeeded in commercial plantings because of this and other faults.

According to Fowler (1865), when Castle Kennedy is "within a few days of being ripe, a clear honey-looking substance of exquisite flavor commences to drop from the eye of each fruit. When quite ripe this substance becomes somewhat viscid, hanging like an elongated dewdrop, from half an inch to three-quarters in length, clear as crystal, giving a very remarkable appearance to the fruit." Moore (1872) reports that Negro Largo grown in pots in England has an open eye and generally a globule of sirup. And Estebich (1910) finds in Spain that Bordissot Negra, when grown in suitable soil, is apt to have in its eye a drop of liquid of a sweet, gummy consistency.

Clear drops of gum from Kadota figs are completely soluble in water and show the following analysis: reducing sugars, 45.53 per cent of the dry weight; total reducing sugars, after hydrochloric acid inversion at room temperature, 46.86 per cent, the sucrose being 1.33 per cent of the dry weight.⁷

Eye Scales.—The surface scales of the eye of the fig may be large, medium, or small, broad or narrow, acute or rounded, with or without scarious margin, same color as body of fruit or of a contrasting color, and flat or erect at maturity. In Turkey and some other figs, the eye scales are pinkish, even in the small green fruit. In mature Fraga and Gota de Mel, the rose-pink eye contrasts beautifully with the green or yellowish body. Almost without exception, eye scales of caprifigs, at least of the profichi crop, assume an erect position at maturity. This is also commonly true in such edible figs as Calimyrna, Adriatic, and Kadota, though in many varieties eye scales remain appressed to the body.

As pointed out and illustrated by Cook (1922), misplaced scales are commonly found in figs. These abnormal figs (fig. 7), with scales near the apex, on the body, or sometimes in a more or less spiral ring, help to explain the structure of the fig receptacle as a shortened, fleshy branch composed of a series of fused internodes, the scales or reduced leaves of which remain distinct.

Merioun (*Fico fetifero*), according to Eisen (1901), has a very large, open eye "emitting one or more small figs similar to the mother fig. . . . The monstrosity of this fig is similar to the one found, for instance, in roses, where the axis is prolonged, forming a new rose; or as in certain citrus fruits, such as the navel orange." Tapa Cartin also "frequently develops a monstrosity—another receptacle cropping out of the apex of the first one" (Eisen, 1901). A fig constricted at the middle by a row of misplaced scales is figured by Gasparrini (1845).

⁷ Material for analysis collected by Sheldon Jackson, Assistant in Agricultural Extension, Merced, California. Analysis by Walton B. Sinclair, Assistant Professor of Plant Physiology and Assistant Plant Physiologist in the Experiment Station.

Iris.—The iris, according to Eisen (1901), “is a colored zone surrounding the scales of the eye, situated between them and the elevated ridge. It is not identical with the ridge itself.” In his variety descriptions, Eisen frequently mentions the iris; for example, he says that Drap d'Or has a small eye “with distinct violet iris” and rosy amber scales. While Eisen defines the iris as being “a colored zone,” he sometimes uses other



Fig. 7.—Deformed figs with misplaced scales help to show that the fig fruit is a shortened, fleshy branch composed of a series of fused internodes, the scales or reduced leaves of which remain distinct.

than color terms in describing it, as in Hirta du Japon, which has, he says, an “iris small, but rough.” Of Martinique White he writes, “eye open, large, with elevated iris”; and of Monaco Bianco, “iris slightly elevated from a surrounding depression, with faint color of dark green.”

Starnes (1903) seldom describes the iris. He states, however, that Brunswick has an “iris with rosy red scales,” thus apparently confusing iris and eye scales. The iris is occasionally mentioned by Hogg (1866) in his descriptions of varieties; for example, of Gros de Draguignan he writes: “The eye is open and has a dark brown, or rather reddish brown, iris round the opening”; and of Panaché: “Eye closed, and with a nar-

row iris round it." Specimens of Panaché grown at Riverside show colored eye scales, but not an iris. According to Rixford (1918), Lob Injir (Calimyrna) has a large, open eye "bordered by whitish protruding scales a little lighter than the skin, surrounded by a dark ring or iris."

The character "iris" has not been used in blank forms for fig variety description at the California Citrus Experiment Station.

Skin.—The skin of a fig, according to Winton and Winton (1935), consists of an outer epiderm of polygonal cells with thickened outer walls, raised stomata, unicellular and multicellular hairs; and of a hypoderm of rounded polygonal cells, some containing small oxalate crystal rosettes. There is no thick cuticle, such as that found in the apple and the grape. The epidermal cells and the unicellular hairs are colorless. The color of dark figs is found in parenchyma cells lying just beneath the epidermis.

In some varieties, such as Mission, the skin of mature fruit can be readily peeled back from the stem end before eating; in others, the skin adheres rather firmly to the meat. Starnes and Monroe (1907) mention the following figs among those that peel readily: Adriatic, Belle Dame, Datte, and Negro Largo. They describe Abruzzes, Celestial, Castle Kennedy, and Monaco Bianco as having a skin which adheres to the flesh. Some canners label their product "skinless figs"—a misleading term. A more correct label would be "skinned figs," since the skin of the fresh figs is removed with lye, as described by Reed (1933) and by others.

The skin may be dull, as in Ischia, or glossy, as in Kadota. In Madeleine, the skin has a beautiful clear waxy appearance. Some varieties, as already mentioned, have a rough surface due to the presence of ribs.

Texture of skin has an important bearing upon the commercial value of the fig. The firm or rubbery texture of the skin of the Kadota, for instance, makes this variety almost ideal for canning purposes (Condit, 1927); the fruit is not easily bruised and can be satisfactorily transported fresh to distant markets. Mission, Calimyrna, and Turkey figs do not have rubbery skins, but they do withstand fairly well the processes of picking and packing for the fresh-fruit market. The skin of such figs as Marseilles is thin, delicate, and easily bruised. Starnes and Monroe (1907) describe the skin of Peau Dure in Georgia as thin but tough and elastic; this fig is therefore deserving of its name, "Tough Skin."

Checking of the skin (fig. 8) is a characteristic of some fig varieties, more common in varieties having thin, tender skin than in those having skin of firmer texture. Both Kadota and Calimyrna show some checking of skin, which does not, however, impair the naturally good shipping quality of these two varieties. Commission men in New York understand that this checking indicates maturity, and unless "too pronounced, there

is no particular objection to it.”⁸ *Euscaire* (fig. 8, *A*) and *Mission* (fig. 8, *B*) show some longitudinal checking, while *Panaché* (fig. 8, *D*) and many others show fine crisscross checks as they mature. Starnes and Monroe (1907) state that the skin of *St. Jean Grise* is medium thick, brittle, and splits at maturity in a network of small “crevasses,” like that of *Ischia*. *Bourjassotte* (*Grise* in England has been described as follows: “When thoroughly ripe, the skin cracks slightly crossways and length-

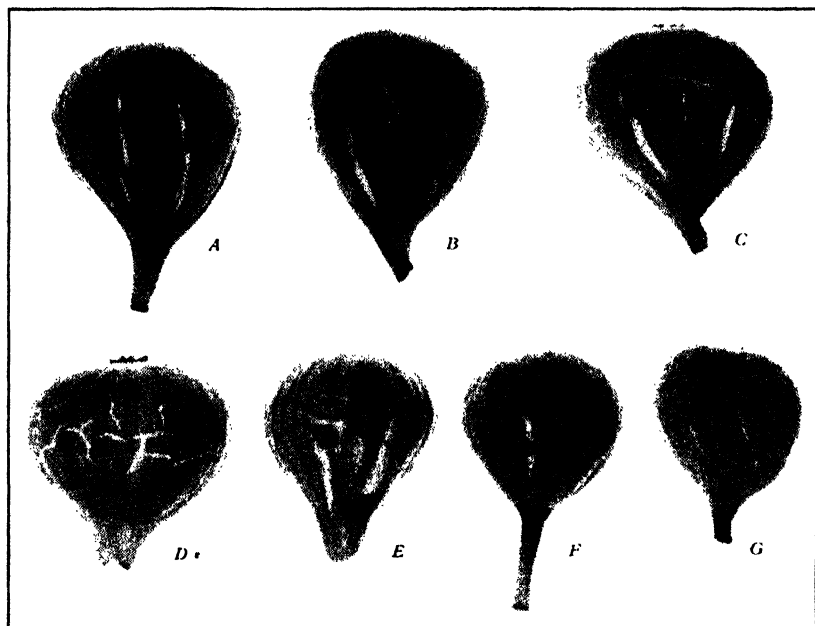


Fig. 8.—Checked skin of different fig varieties: *A*, *Euscaire*; *B*, *Mission*; *C*, *Fraga*; *D*, *Panaché*; *E*, *Gota de Mel*; *F*, *Pastiliere*; *G*, *St. Jean Grise*. ($\times 0.6$.)

ways over the whole surface, allowing the juices to exude and to stand out like drops of dew” (M., 1871).

Checking of the skin is a character which denotes a good fig ready for eating. A Spanish proverb describing the perfect fig reads: “A neck for the hangman, a robe for the beggar, a tear for the penitent.” And Mary Boyd (1911) states that the figs which she bought in Majorca had all the required attributes of perfection: the slender neck, the rent in the skin, the oozing drop of juice.

Bloom.—A surface character present in some figs is the bloom. Miller (1768) reported of *Genoa Black* that the skin “hath a purple farina over

⁸ McDonald, M. H. In letter to author from California Fruit Exchange, New York City, September 27, 1939.

it like that on some plums." But according to Waugh (1908), the bloom of fruits has no real color or is merely waxy gray, the apparent color coming from the underlying skin. Bloom, therefore, is best described by such terms as "prominent," "moderate," "thin," "delicate."

The prominent bloom of such purplish-black figs as Mission and Pastiliere is pruinose. Eisen (1901), describing the bloom of Celeste, states that it "is confined to the neck and upper part of the body, is bounded by a distinct and sharp line, and is thick and pale blue." Apparently this zonation of bloom is not a constant character in Celeste, since at Riverside it is seen only in occasional specimens. According to Reed,^o it is not a characteristic of Celeste in Texas. Eisen (1901) wrote of Grosse Grise Bifère as follows: "Bloom a very fine violet-pearl gray extending to the cheek, but not to the apex zone from which it is separated by a distinct line, between which and the apex there is no trace of the bloom. This is the most characteristic feature of this fig." This describes accurately the bloom character found in St. Jean Grise (fig. 8, *G*) grown at Riverside and tends to show that this variety is the same as that described by Eisen about forty years ago.

Flecks.—The skin of most immature figs shows numerous white flecks or spots scattered over the surface (fig. 9). Brookshaw (1812) stated that Malta Brown is spotted or speckled with small whitish flecks. These flecks are a more important variety character than Eisen (1901) leads one to believe, as he states only that the skin "may be dotted over with light specks or large spots." The flecks vary in size from small indistinct spots to large conspicuous dots scattered more or less thickly over the surface. In Verdal Longue (caprifried), the flecks are often 1 mm in diameter. On most green figs, the white flecks persist until full maturity, then gradually fade. On deeply colored figs, the flecks either become masked by violet or purplish black or are still in evidence as reddish-brown dots. On Toulousienne (fig. 9, *C*) and on Pasquale, the flecks are elongated, frequently 2 to 2½ mm long by ½ mm wide, especially at the apex of the fruit. Large flecks, 2 to 3 mm long, are conspicuous on the basal half of Turkey figs. Rixford (1918) stated that Lob Injir (Calimyrna) has scattered white dots, some of which are elongated.

Hairs.—The epidermis of most fig fruits is studded more or less thickly with unicellular attenuate hairs interspersed with multicellular capitate hairs (fig. 10). A unicellular hair is figured by Tschirch (1889, p. 254, fig. 270). According to Winton and Winton (1935), who figure both kinds of hairs, "the unicellular hairs of the outer periderm are pointed and thick-walled, varying from short to long."

Varieties of figs differ markedly in the abundance and prominence

^o Reed, H. M. In letter to author from Angleton, Texas, September 12, 1939.

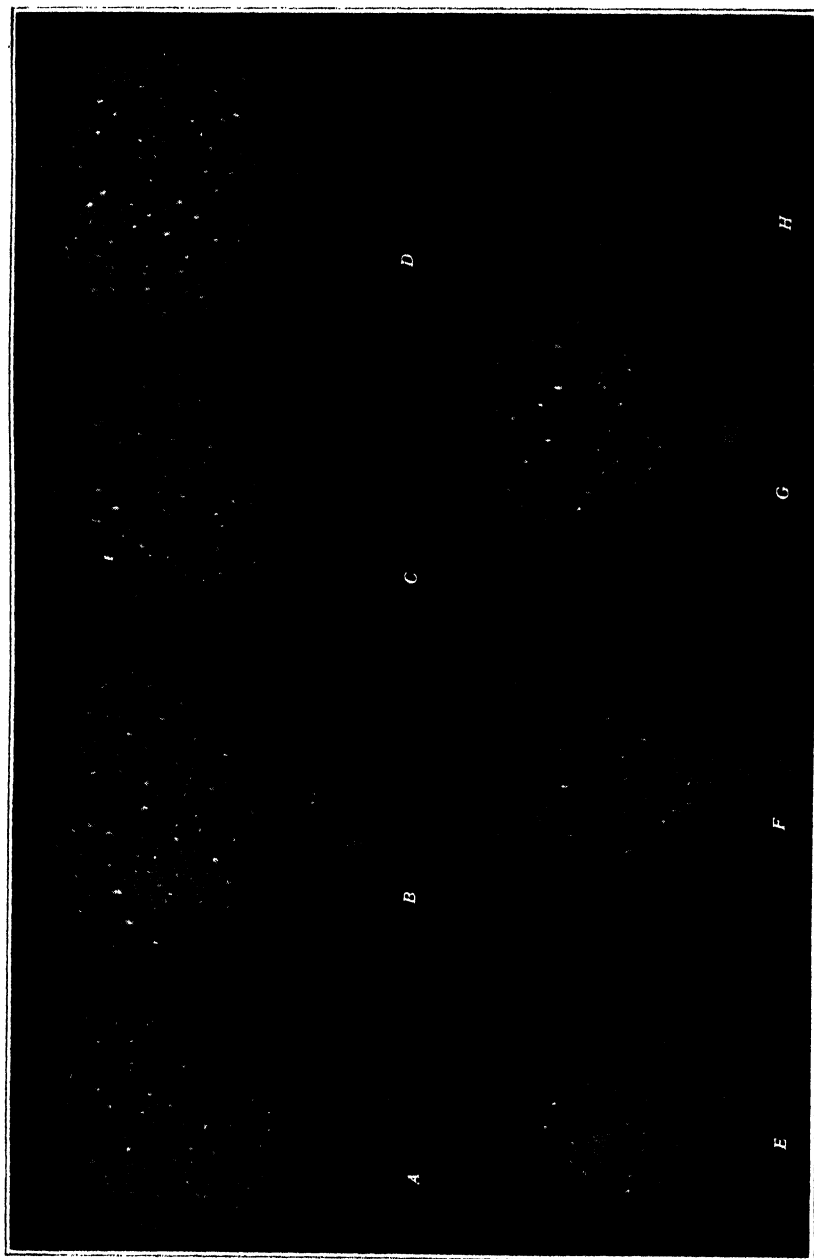


Fig. 9.—White flecks on fruit of different fig varieties: *A*, Barnissotte; *B*, Brunswick; *C*, Toulousienne; *D*, Violette de Bordeaux; *E*, Bourjassotte; *F*, Mission; *G*, Kadota; and *H*, Ischia. ($\times 0.85$.)

of hairs on the epidermis of the fruit. Monaco Bianco and Hirta du Japon (literally, "hairy fig of Japan") both show very prominent hairs. On the Turkey fig, hairs are more numerous and more prominent than



Fig. 10.—Both unicellular attenuate hairs and multicellular capitate hairs occur on the surface of the fig fruit. (Photomicrograph by F. M. Turrell; magnification, $\times 380$.)

on Kadota. For example, on a section of epidermis 6,930 μ long from a Kadota fig, 16 unicellular and 3 capitate hairs were counted; while on a similar section from the epidermis of a Turkey fig, there were 38 uni-

TABLE 3
COMPARATIVE MEASUREMENTS OF EPIDERMAL HAIRS OF FRUIT OF
DIFFERENT FIG VARIETIES

Variety	Unicellular hairs				Capitate hairs		
	Number measured	Average length	Longest hair	Average thickness near base	Number measured	Average length	Average thickness near base
<i>Ficus Carica</i> var. Kadota....	15	μ 58.6	μ 113.2	μ 17.7	4	μ 38.8	μ 16.9
<i>Ficus Carica</i> var. Turkey....	11	189.3	360.0	31.6	5	37.9	15.2
<i>Ficus palmata</i>	8	186.9	309.6	24.9	3	35.4	16.3
<i>Ficus Pseudo-Carica</i>	9	145.7	360.0	22.3	3	29.2	16.3

cellular and 13 capitate hairs. Abundance and harshness of the hairs can be roughly determined by rubbing the surface of the mature fruit over the tender skin of arm or cheek.

Measurements of hairs of 4 fig varieties, representing 3 species (table

3), show considerable variation in length and in thickness near the base. The longest hairs of Turkey, for example, are over three times as long as the longest found on Kadota. Capitate hairs of the 4 varieties are remarkably uniform in size and shape.

Unicellular hairs appear transparent in fresh sections of fruit; capitate hairs have a brownish coloration. Unicellular hairs are brittle and are very subject to injury while material is being prepared for sectioning and mounting. They stand out at right angles to the surface of the

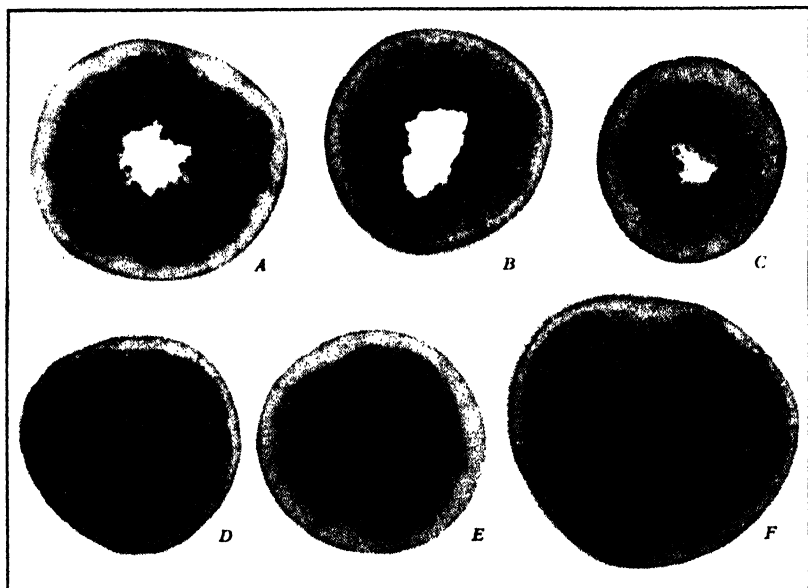


Fig. 11.—Meat and pulp of different fig varieties: *A*, Turkey; *B*, Brunswick; *C*, Madeleine; *D*, Barnissotte; *E*, Kadota; *F*, Calimyrna. All except *A* and *C* are capped and have fertile seeds. ($\times 0.66$.)

fruit, whereas capitate hairs recline at an angle of approximately 45° . A capitate hair ordinarily consists of a stalk and a four-celled body, oblong or obovate in shape. Unicellular hairs of *Ficus Pseudo-Curica capri* arise from prominent papillae or nipplelike protuberances. Some of the epidermal cells of the papillae show a purplish pigmentation.

Hairs on fig fruits (and leaves) are partly responsible for irritation of the skin suffered by some fig pickers. According to Davidson (1899), "these prickly hairs readily penetrate the flexor surfaces of the fingers and wrists, and in individuals with irritable skins a dermatitis follows in twenty-four hours... probably produced by the mere mechanical presence of the bristle-like hairs, as examination shows that the hair points are solid at the tip" but hollow at the base when mature.

Meat of the Fig Fruit.—The meat of the fig is that part lying between the skin and the pulp (fig. 11). It is generally white, but is sometimes colored. In first-crop Kadota figs the meat is streaked with violet. The same is true of a variety in the Citrus Experiment Station collection under the name of Monstreuse.

The meat may be thick, medium thick, or thin. Thickness of meat is usually correlated with size of fruit, the larger figs having the thicker meat. Some actual measurements are shown in table 4. Thickness and

TABLE 4
THICKNESS OF MEAT IN RELATION TO SIZE OF FIG*

Variety	Size of fruit	Range of body diameter	Range of meat thickness
		mm	mm
Celeste.....	Small	23-32	1.5-3.0
Ischia.....	Below medium	30-42	2.0-3.0
Precoc de Barcelone.....	Below medium	31-39	1.5-2.0
Mission.....	Medium	37-51	2.0-4.0
Castellana.....	Medium	40-43	4.0-4.5
Marabout.....	Large	52-58	3.5-5.0
Sultane.....	Large	48-55	3.0-5.0
Turkey.....	Large	47-54	3.5-6.0

* Measurements made on ten figs of each variety.

texture of meat have some bearing upon the value of caprifig varieties. Thus Condit (1922, p. 352) reports that

The texture of profichi figs varies somewhat in different varieties. Some have a thick pithy meat or rind which contains considerable moisture and resists drying. Such figs, known by some growers as "wet figs," are favored, since they presumably enable the insects to issue over a longer period after the figs are placed in the baskets. Markarian No. 2 and Roeding No. 3 are of this nature. Other figs are known as "dry figs," since the meat is thin and dry, Roeding No. 1 and No. 2 and *Pseudocaria* being typical examples.

This distinction between "wet" and "dry" profichi figs is not a very important one, however, as blastophagas apparently issue freely from both kinds. On the other hand, caprifigs with thick meat, inclined to become pulpy, attract and harbor *Carpophilus* and other beetles which carry fruit-spoilage organisms.

The rubbery texture of certain figs, such as Kadota, is partly due to the firmness of the meat. Such figs when dried, often have a thick, woody meat which is difficult to process for fancy packing. The texture of meat in dried figs is influenced both by climatic conditions during the ripening period and by methods used in the drying process. Excessively high temperatures ripen figs prematurely, toughen the skin and meat, and

increase the proportion of overdried leathery fruit. Starnes and Monroe (1907) use the terms "spongy," "very spongy," "slightly spongy," "firm," and "fibrous" in describing the texture of fig meat.

Pulp.—The pulp of the fig consists of the inner part of the meat, the floral peduncles and the perianth, the parenchymatous outer cell wall of the ovaries, and the seed. The parenchyma cells of the floral organs become greatly enlarged or swollen and serve as storage tissue, as described by Condit (1932). The flowers as they mature may completely fill the cavity and form a solid pulp, as in most, but not all, caprifiged figs, whether of Smyrna or common type. In many common figs, such as Turkey, Brunswick, and Madeleine (fig. 11, *A*, *B*, and *C*), the mature flowers do not fill the cavity, and the pulp is therefore hollow at the center. "Hollow center" is mentioned by Eisen (1901) in descriptions of Gouraud Rouge, Royal Vineyard, and other figs.

The mature pulp may be white, as in Marseilles, Osborn, and Croisic (Cordelia), or it may become somewhat amber yellow as the fruit softens, though in the majority of figs it is some shade of strawberry. A few figs, such as Beall and Euscaire, which are purplish black externally, have an amber-white pulp. Eisen (1901) wrote of Pied de Boeuf: "A very good fig, remarkable on account of the color of its pulp, which is amber, while the skin is dark." However, Pied de Boeuf grown in the Citrus Experiment Station variety plot at Riverside shows a strawberry pulp. Mission, Turkey, Adriatic, and Genoa are other examples of figs having a light-strawberry pulp. Light strawberry corresponds to "shrimp pink," and medium strawberry to "jasper red," as designated by Ridgway (1912). Deep strawberry or blood red as seen in the pulp of caprifiged Adriatic corresponds to "blood red" of Maerz and Paul (1930). As previously reported (Condit, 1927), Kadota brebas have a pulp which is distinctly violet-tinted. Second-crop Kadota figs show an amber pulp in hot interior valleys but a violet-tinted pulp in cool coastal climates. The pulp of Calimyrna is either amber yellow or a very light strawberry.

The fact that Kadota in California and Brunswick (Magnolia) in Texas have an uncolored pulp is another reason for their being especially adapted to canning, for the finished product is thus attractively clear throughout. White Pacific and Kadota (both identical with Dottato of Italy) have long been regarded by some as distinct varieties on account of skin and pulp-color variations. The effect of caprification upon color of pulp and upon other fruit characters of common figs is discussed in a later section of this paper ("Effects of Caprification," p. 32).

On the basis of internal color, there are two classes of caprifigs inhabited by blastophagas: (1) those like Stanford, Palmata, and several of the Maslin seedlings, which are white inside; and (2) those like Roed-

ing No. 3, Milco, Samson, and Excelsior, which have the inner part of the meat and the flower stalks colored violet-purple.

The pulp constitutes about 83 per cent of a mature fig, the meat and adhering skin forming the rest of the fruit. Comparisons between skin and pulp weight of a few varieties are given in table 5. As the fig matures and dries, the following changes take place. The moisture content decreases from about 80 per cent to 16 per cent or less; the sugar content increases from around 16 per cent to 60 per cent or more; the individual flowers lose their identity; and the pulp becomes a more or less coherent, sirupy, or gummy mass enveloping the seeds.

Colby (1894) in his fruit descriptions apparently referred to the flesh as including meat, juice, and pulp, and gave the proportion of juice

TABLE 5
PROPORTION OF SKIN TO PULP IN CERTAIN SECOND-CROP FIGS

Variety	Number of figs in sample	Per cent skin (including stalk)	Per cent pulp
Celeste.....	35	21.0	78.9
Euscaire.....	20	17.2	82.7
Mission.....	32	16.7	83.2
Precoce de Barcelone.....	23	13.7	86.2
Turkey.....	18	15.0	84.9

to pulp as follows: Rose Blanche (the juiciest fruit), 90 per cent juice; Missone, 88.6 per cent; Brunswick, 86.7 per cent; and very dry fruit such as Coucourelle Blanche, only 38.5 per cent juice. Traub and Fraps (1928) show that the fresh Magnolia fig in Texas consists of 14.7 per cent skin and 83.3 per cent pulp, while the moisture content averages 74.8 per cent. Colby (1894) described California Black as having a coarse flesh; Constantine, a hard and fibrous flesh; Du Roi, a hard and rather dry flesh; Adriatic, a firm and solid flesh; and Brunswick and certain others he described as being full-fleshed. Of all California fresh fruits, the fig is probably the most difficult to put on the market in a state approximating the texture and quality of figs allowed to mature properly on the tree. For this reason, Colby's notes would be more conclusive had they been made on mature, freshly picked fruits selected in the orchard, rather than on miscellaneous fruits after they had been shipped 250 miles to Berkeley.

Coarse texture of fig pulp is indicated by large, conspicuously swollen flowers and flower parts. Starnes and Monroe (1907) seldom if ever described the pulp as coarse, but they did use such descriptive terms as "fine-grained," "delicate," and "smooth." Eisen (1901) described pulp

texture of fruits as follows: *Blanche*, "very juicy, finely grained"; *Bontard*, "usually coarse and uneven, but sometimes . . . fine-grained"; *Martinique*, "very sirupy and juicy"; *Datte Quotidienne*, "thick, oily." He did not signify what was meant by "oily" pulp. At *Riverside*, *Mission*, *Kadota*, and *Adriatic* figs show a pulp of fine texture, while *Castellana*, *Marabout*, and *Euscaire* have a coarse-textured pulp. Some figs, notably *San Pedro* and *Dauphine*, when mature, show a gelatinous consistency of juice in the pulp.

Seeds.—Seeds, fertile or infertile, are characteristic of fig fruits. As previously pointed out (Condit, 1932, p. 459), such varieties as *Mission*, *Turkey*, and *Marseilles* have numerous hollow and infertile achenes with the ovary wall fully sclerified. Other varieties with infertile achenes, such as *Dottato* (*Kadota*) and *Brunswick* (*Magnolia*), do not have the ovary wall so fully sclerified nor so well developed as in the plump achenes of most common figs. To call such figs seedless is incorrect. Traub and Fraps (1928) record an average of 406 infertile achenes in *Magnolia* figs. Price and White (1902), also Starnes (1903), refer to the infertile seeds of common figs as "seed rudiments."

According to Winton (1916), "the stone cells of the sclerenchyma in the ovary wall of fig flowers are sufficiently characteristic of the species to enable their identification in food preparations such as marmalade, jam, and coffee substitutes." Winton reproduces the account and illustrations of Moeller (1886), showing that the outer sclerenchyma consists of a single layer of small stone cells, 15 μ in diameter. The endocarp or inner sclerenchyma is composed of one or more layers of rounded or angular stone cells about 50 μ in diameter. Each cell has a narrow lumen and thick walls with distinct, concentric layers perforated by branching pores.

Fig seeds may be large, medium, or small, few or many, conspicuous or indistinct. According to Eisen (1901), "The size of the seeds of the imported *Smyrna* figs may be considered as a standard with which to compare others." Seeds of *Marseilles*, though infertile, are unusually conspicuous, partly because they stand out sharply against the background of white pulp. Starnes and Monroe (1907) describe seeds as few, small; and seed rudiments as large, crisp, crackling under teeth, large and numerous, medium to large, small to medium, yellow, numerous, buff, soft. Eisen (1901) only occasionally mentions the seeds in his descriptions of fig varieties and then describes them as few, small, large, exceedingly minute, few but very large, large flattened, amber in color, very hard.

In 1936, an experiment was conducted at the Citrus Experiment Station to determine whether either *xenia* or *metaxenia*, or both, occur in

the Calimyrna fig. In the caprification of this variety, 10 different capri-figs were used, and 10 lots of seed were secured. Careful examination of seeds of each lot under a low-power binocular (6× eyepiece and 55-mm objective) failed to reveal any consistent differences in size, shape, markings, or color. The seeds were somewhat flattened, slightly pointed or protruding at the hilum, ridged somewhat along one side, very minutely pitted over the surface, and light chestnut in color. Five hundred seeds of each lot showed an average weight of 0.62 gram, the range being from 0.55 to 0.67 gram.

The number of seeds found in figs is surprisingly large. Rixford (1918) reports an average of 1,600 fertile seeds in each of three capri-

TABLE 6
NUMBER AND WEIGHT OF SEEDS IN CAPRIFIED COMMON FIGS

Variety	Number of figs in sample	Average number of seeds per fig			Weight of 500 seeds, grams	
		Sterile	Fertile	Total	Sterile	Fertile
Adriatic*	11	611	986	1597	0.2395	0.5800
Celeste†	19	56	187	243	.2605	.5740
Kadota‡	8	199	719	918	.2052	.5647
Kadota†	16	30	537	567	.2105	.5420
Mission†	9	292	408	700	.2202	.4775
Precoce de Barcelonette	23	187	215	402	.2600	.4577
Turkey†	15	115	967	1082	0.1820	0.4627

* Dried figs from Merced.

† Fresh figs grown at Riverside.

‡ Dried Figs from Fresno.

fied Adriatic figs. My records show (Condit, 1922) that in Adriatic, fertile seeds in 11 caprified specimens varied in number from 472 to 1,288; in 4 caprified Kadota figs, fertile seeds numbered as follows: 544, 412, 402, and 667. Mauri (1939b) lists 18 varieties of Kabylean figs and gives the average number of seeds as determined from a 5-fruit sample of each variety. Fertile seeds ranged in number from 716 to 1,831 per fig; sterile seeds, from 15 to 218. If fig seeds are immersed in water, fertile seeds can readily be separated from those that are infertile or sterile, for the fertile seeds sink, while the lighter, sterile seeds come to the surface. Recent studies of seeds in caprified common figs are summarized in table 6.

Flavor.—Flavor in figs, as in many other fruits, is a difficult character to describe. Some figs, such as Mission, have a peculiar flavor which may be described, though inadequately, as a distinctive fig flavor. Kadota is sweet but lacks character or distinct flavor (Condit, 1927). Edible figs of *Ficus palmata* Forsk. and most of its hybrids with *F. Carica* have a strong, disagreeable flavor making them definitely unpalatable.

Many caprifiged common figs and some Smyrna-type figs have a distinct acidic taste. Lindley (1831) wrote of Nerii: "It is much the richest of its species and there is in its juice a slight degree of very delicate acid which renders it peculiarly agreeable to most palates." Eisen (1901) compared Atwater with Peters White and stated that "the latter has less vinous acid." Starnes and Monroe (1907) said of Peau Dure: "quality very good, distinctly vinous, a very unusual characteristic with figs and rendering this variety unique." Grasovsky and Weitz (1932) refer to the pulp of N'eimi as "sour-sweet in taste" and to that of Sharrawi as "sourish in taste." Of Hmadi they write: "variety also considered to be a delicious fresh fig by many fellaheen, mainly due to its sour-sweet sub-acid taste."

Edible figs of *Ficus Pseudo-Carica* Miq. have a decidedly acid flavor. This character is also pronounced in some seedlings having *F. Pseudo-Carica* caprifig as the male parent. The juice of uncaperfiged Kadota figs in August, 1939, showed 13.2 mg of citric acid; caprifiged figs of the same variety showed 14.0 mg; while a seedling of Calimyrna $\times$ *F. Pseudo-Carica*, which had an especially sour taste, showed 44.3 mg of citric acid.¹⁰

Other terms used in describing flavor are: "sweet," "rich," "highly flavored," "lacking flavor." Such terms as "agreeable," "exquisite," and "poor," apply more to one's opinion of quality than to flavor. Fresh figs lack any such well-defined aroma as that found in some vinifera grapes (Bioletti, 1938). As with most fruits, marked differences in fig flavors can be distinguished only by those who have a delicate sense of taste.

Quality.—Terms describing quality of fig fruits, as pointed out by Waugh (1908), "are all relative, and all express a personal judgment. Men may honestly disagree as to quality." Quality depends to a considerable extent upon the use to which a fruit is put. Thus, there is little disagreement over the opinion that Magnolia fig in Texas and Kadota in California both have excellent canning quality; or that the shipping quality of fresh Calimyrna, Kadota, Turkey, and Mission figs is good to very good; or that Calimyrna, Adriatic, and Mission have excellent drying quality. Eisen (1901) says of Cotignana: "very inferior in quality as fresh, but superior for drying." General terms used in designating quality in figs are as follows: poor, inferior, medium, fair, good, very good, superior, fine, excellent.

Effects of Caprification.—Caprification, which results in the formation of fertile seeds, markedly affects most common figs in size, color of skin, color of pulp, tendency to split, texture, flavor, quality, and in com-

¹⁰ Juice samples prepared and titrated by Walton B. Sinclair, Assistant Professor of Plant Physiology and Assistant Plant Physiologist in the Experiment Station.

mercial value. These effects, described by Condit (1927), are especially noticeable in the Kadota variety. Some black figs like Mission and Turkey are not externally changed to any great extent by caprification, and caprified specimens are difficult to distinguish from uncaperified ones.

In general, caprified figs are larger than uncaperified figs of the same variety. For example, at Riverside, 32 caprified Celeste figs averaged 30.8 mm in diameter and 17.2 grams in weight, while 16 uncaperified figs averaged 26.6 mm in diameter and 11.8 grams in weight; and 50 caprified Kadota figs averaged 44.4 mm in diameter and 45.4 grams in weight, while 50 uncaperified figs from the same or neighboring trees averaged 38.1 mm in diameter and 32.3 grams in weight. Caprified Brunswick figs, also, are considerably larger than those that are uncaperified. Ischia, however, is apparently little affected in size by caprification, for various-sized specimens can be found in both caprified and uncaperified figs of this variety.

The skin of normally yellow or greenish-yellow figs, such as Kadota, Fraga, and Adriatic, remains a grass-green color in caprified specimens, even at full maturity. The normal bronze color of uncaperified Celeste and Brunswick figs becomes darker and shaded with violet if their fruits have fertile seeds. Verdal Longue figs that are caprified show a much deeper violet color of skin than do uncaperified specimens.

Leclerc du Sablon (1908) states that in studying 3 varieties of common figs, he found it easy to recognize by external appearance the specimens having fertile seeds: Caprified fruits of Madeleine, for example, are larger and fleshier than those that are uncaperified, their exterior color is violet-gray instead of yellowish gray, and the pulp is rose color rather than golden yellow. The comparative average weights of caprified and uncaperified figs of the 3 varieties he found to be as follows: Madeleine, 37 and 29 grams, respectively; Datte, 23 and 20 grams; Bourjassotte Black, 68 and 40 grams.

Although caprification affects color of pulp of most figs, some common figs, such as Marseilles, show a white pulp whether caprified or not. Most common figs, such as Kadota, Osborn, and Brunswick, which normally have an amber or uncolored pulp, have strawberry-colored pulp when caprified. The strawberry pulp of Adriatic, Turkey, San Pietro, Barnissotte, Col de Dame, and Verdal Longue becomes much deeper strawberry or even blood red when the fruit is caprified. Fertile seeds in mammoni caprifigs, as pointed out by Rixford (1918), are found in flowers with red succulent perianth lobes; these flowers are accordingly readily distinguishable from the white or violet, dry gall flowers containing blastophagas.

Fertile seeds and flower parts pack the interior of the fig more or less

solidly. The swelling of these flower parts during the later stages of fruit maturity often creates an expansive force which the meat or receptacle wall cannot withstand. The result often is a splitting of the fruit at the apex (fig. 6), described by Condit (1918b, 1919). Celi (1907) concluded that caprifiged figs have a greater tendency to split and, further, that caprification increases the size of the fruit but injures the quality. Splitting of caprifiged figs is generally not serious in California except in periods of unusual weather during the ripening season—that is, high humidity, showers, or cool nights followed by hot days.

The effects of caprification of common figs in relation to quality are discussed by Eisen (1901), Celi (1907), Leclerc du Sablon (1908), Rixford (1912, 1918), Condit (1922), and by Bobone (1932). As pointed out by Bobone, caprifiged figs ordinarily have a pulp texture coarser than that of uncaperfiged figs of the same variety. This is due to the larger and more swollen flower parts of the caprifiged specimens. The excellent flavor and quality of Calimyrna figs are due in a considerable degree to the oily or nutty kernel of the fertile seeds; fertile seeds in common figs also have a nutty flavor which is imparted in some degree to the pulp. Rixford (1918) stated that a caprifiged fig "is considerably increased in size, and the seeds contain plump kernels which give a delicious nutty flavor not apparent in uncaperfiged figs. Dr. Eisen was the first investigator to make the suggestion." Caprification of common figs, however, often results in an increased amount of fruit spoilage.

Taylor¹² writes on the subject of the caprification of common figs as follows:

... Adriatic, Mission, and Kadota should never be caprifiged. While the size of the fruit is improved, the quality is definitely impaired. I do not have in mind endosepals or rot. Clean capris might overcome that particular hazard. I am, however, convinced that the skin, texture, flavor, and color are impaired by caprification. The skins are made thick and pulpy in each case. The meat of the Adriatic is turned to a dark purple and has a decidedly increased acid flavor. With Black Mission, the outside color is a lustreless blue instead of the rich black, and the meat is coarse and stringy. Kadota seems affected principally towards a thick, pulpy, rough skin.

LATEX

Latex cells or tubes are characteristic of certain families of plants including the Moraceae. According to Strasburger *et al.* (1912, p. 80),

... latex cells ... arise from cells which are already differentiated in the embryo. Growing as the embryo grows, they branch with it and penetrate all its members, and may thus ultimately become many metres long. ... They are provided with a peripheral layer of living cytoplasm and numerous nuclei. Their sap is a milky, usually white fluid, which contains gum-resins, *i.e.* mixtures of gums and resins,

¹² Taylor, Charles. In letter to author from Fresno, California, October 6, 1939.

caoutchouc, fat and wax in emulsion. In addition, they sometimes hold in solution enzymes, leptomin, tannins, often poisonous alkaloids, and salts, especially calcium malate, also in the case of *Ficus carica* and *Carica papaya* peptonising ferments.

The latex cell, then, is a single cell, the growing tips of which make their way through the tissues much as the hyphae of a parasitic fungus penetrate between the cells of a plant. According to Flückiger and Tschirch (1887), latex cells of the fig are so striking that by means of them, one may easily recognize an adulteration of "fig coffee." Winton (1916) states that these tubes in the fig are chiefly remarkable for their numbers and that numerous minute granules, colored intensely yellow by iodine, are suspended in the milky contents.

Solereder (1908) found that in *Ficus Carica* and certain other species of Moraceae "the contents of the laticiferous tubes include large grains, the nature of which has not been determined." The grains frequently show stratification, as first observed by Caruel (1865). Popovici (1926) found that by fixation of latex cells of *Ficus Carica* by Regaud's method, the individuality of the vacuoles was retained. He says (see Moyer, 1937): "... it was found that the single vacuole contained latex. Many fusiform nuclei lay in the envelope of cytoplasm while droplets of caoutchouc were seen both in the cytoplasm and in the vacuole, where they were larger."

Several investigators have studied the enzyme present in the latex of the fig. Bouchert (1880) proved that there is a strong ferment in fig latex capable of digesting albuminoid substances. Gerber (1912*a, b*) studied the latex of the fig in comparison with that of the paper mulberry and found that the fig latex is a vegetable pancreatic juice with proteolytic diastase predominating; that it contains a lipase which is one twelfth as active in a neutral medium as that of the paper mulberry; and that its starch-splitting properties are one eighth as strong as those of the latex of the latter. Its power to coagulate milk, however, is one-hundred times as great as that of the paper mulberry. Gerber and Guiol (1912) found that pancreatin from fig latex has twice the proteolytic activity of Merck's trypsin and that its amylolytic activity is slightly greater. Gerber (1913) also reported that latex of mulberry, fig, and paper mulberry each hydrolyze carbohydrates and proteins.

Gerber and Salkind (1913) determined that subcutaneous injections of fig latex into a pigeon, produced fever, local congestion, lesions of a necrotic character, convulsions, and finally death in a state of coma. According to Gerber (1914), the casease and trypsin of latex of fig and paper mulberry are the same. Deleanu (1916) found that the peptolytic enzyme from fig latex is identical with that from papaya. Robbins and Lamson (1934) examined the enzymatic activity of the sap from four

genera of Moraceae and found it less than one fifth of that noted in sap of *Ficus Carica* collected in Alabama at the same time. The concentration of enzyme has a marked seasonal variation, according to Robbins (1935), and is lowest in early summer.

Latex cells are found in the cortex of root and stem and in the parenchyma of leaves and fruit. According to Tippo (1938, p. 16), "the latex tubes in the Moraceae may vary from small to large. There may be few or many in the xylem . . . usually in the center of a ray, rarely near the top." Healthy fig trees show a copious exudation of latex from the bark, but frost or drought may injure the latex tubes. The degree of frost damage to young fig trees can be ascertained by slitting the bark with a knife and noting the decreased amount of exudation; nursery trees badly frozen or dried out show no latex and should not be planted.

Some species of *Ficus* have been used for the production of rubber, and it is not strange, therefore, that the possibilities of utilizing the latex of *F. Carica* have been considered. One writer (Anonymous, 1928) reports that rubber in commercial quantities may be obtained from the Panaché, or French fig, and that the common California varieties, Kadota and Adriatic, are being subjected to research processes. The fig and many other latex-producing plants are not being used as sources of rubber, however, since other and cheaper sources are available.

Merezhkovskii (1931, p. 16), in his *Romance of Leonardo da Vinci*, states that the latter suggests fixing "the temper for the color [of paints] with the yolk of an egg and the milky sap of young branches of the fig tree, mixed with water and wine."

As previously stated (see "Hairs," p. 23-26), fig pickers sometimes experience an acute irritation of the skin, due partly to the hairs on fruits and leaves. Since the same sensation occurs while handling fresh fig wood when budding, grafting, or making cuttings, and especially when picking mamme caprifigs from leafless trees in late winter, the latex, also, must cause irritation. Maiden (1909) reported that "the irritation caused by the skin of the common edible fig is so well-known that people usually peel it before eating it; if they omit to do so, they are reminded by the irritation of the mouth."

Schwartz and Tulipan (1939, p. 439) in their book, *A Text-Book of Occupational Diseases of the Skin*, include a paragraph describing dermatitis from figs. Legge (1921) gives an account of a similar dermatitis among dried-fig packers and states that "the abrasive action on the cuticle of the hands of the operators when pulling open the dried figs, permits directly this protein enzyme to produce a digestive and dissolving action of the tissues and is the etiology that is responsible for the lesions." The preventive measures offered are the use of cotton gloves in

picking fresh figs or the anointing of the hands with a high-grade mineral oil, such as the lighter automobile lubricants. According to Gould (1919), "some pickers wear gloves or rubber finger tips. Others smear beef suet or some other form of grease or oil on the hands and also on the arms where the latter are exposed." Frequent washing of the hands in vinegar helps to counteract the effect of the juice. Gasoline is also effective in removing latex, although most pickers depend primarily upon strong soapsuds and water.

THE LEAF

Leaf characters of taxonomic value in the fig are similar to those described by Bioletti (1938) for the grape. In the fig, these characters include form of leaf, size, sinuses, margin, color, surface, texture, petiole, and cystoliths; and they are sufficiently stable in fig varieties to be of value in classification and identification. For example, Miller (1768) in describing Brunswick or Hanover fig stated that the leaves are much more divided than those of most varieties. And Brookshaw (1812) reported that Ischia Green "has a small leaf in comparison to some others and is not much divided."

Considerable variation exists in forms of leaves from a single tree. Juvenile fig leaves in general show much deeper sinuses and narrower lobes than leaves on fruiting branches. A single leaf typical of the variety must, therefore, be selected with considerable care. Starnes and Monroe (1907) illustrate a single leaf as typical of a variety, as does Mauri (1939*a*) in his study of caprifigs. The latter, however, in his treatment of edible figs of Algeria the same year (Mauri, 1939*b*), illustrates nine leaves of each variety to show the variation in a single variety.

Swingle (1905) described in detail the leaf characters of 7 varieties of Neapolitan caprifigs and presented a key for their identification, based on length of petiole as compared to depth of sinuses, width of sinuses, apex of middle lobe, and decurrence of lamina.

Form of Leaf.—Starnes (1903), after a close study of the foliage of some 25 fig varieties in Georgia, decided that there are apparently five distinct forms or types of fig leaves. Four of these he named as follows: "okra," "grape," "maple," and "oak," after the plant which each chanced to resemble; the other leaf type he named "spoonbill." Starnes and Monroe (1907, p. 54) changed these names and published the following leaf chart:

Type I. Cordate—base rounded; no subdivisions or groups:

(Transition to type II.)

Type II. Calcarisate—base spurred; 4 subdivisions or groups.

Group 1. Latate—lobes broad.

(Transition to group 2.)

Group 2. Lyrate—lobes incised.

(Transition to group 3.)

Group 3. Spatulate—lobes spoon-like.

(Transition to group 4.)

Group 4. Lineate—lobes narrow.

These authors state that this classification

... will be found to contain, in many cases, amorphous or varying types of foliage that seem to prevail while the trees are young; but this apparent tendency to amorphism more or less disappears as the specimens attain age, although it frequently persists and occasionally causes some confusion in deciding into which of two divisions certain varieties should be placed.

Of the value of this arrangement, there can be no question, since it has greatly simplified our initial work, limited though it may have been, and the process will prove of much greater value when a more critical comparison becomes necessary as the study proceeds.

In his descriptive catalogue, Eisen (1901, p. 206) briefly describes leaves of the principal fig varieties and reports that, in general,

The leaves are either "large" or "small," "entire" or "deeply lobed," "dark" or "light," "glossy" or "hairy," "regular" or "lop-sided." The lobes are either 3, 5, or 9 in number, or the margin may be "entire." They may be "acute," "pointed," "rounded," "obtuse," "cuneate," "wavy," or "smooth." As the leaves vary on each tree, an average leaf adjoining a fig should always be taken as a model for description. Finally, it should be stated whether the stalk of the leaf is unusually "short" or "long," "dark" or "light."

Both Vallese (1909) and Estelrich (1910) pay some attention to leaf characters in their descriptions of fig varieties. Vallese not only describes the foliage, but gives an outline sketch of two typical leaves. Of the Italian Dottato (synonymous with Kadota of California), for example, he writes as follows:

Leaves scabrous with some rigid, sharp hairs in the spaces between the veins; the color deep green on the upper surface, pale green and velvety below; lamina asymmetrical, longer than broad, almost always three-lobed, more rarely five-lobed or entire; lobes short, obtuse, the middle one cordate, the lateral ones triangular, the superior lobe of the five-lobed leaf hardly at all acute; sinuses large, very shallow; petiolar sinus in the form of a V-opening, often very broad and almost absent; teeth small, obtuse, irregular; veins projecting prominently from the lower surface, of the same greenish-yellow color as the stalk.

It is interesting to compare this Dottato leaf sketch by Vallese with a photograph of 35 Kadota leaves, all taken from a single tree (Condit, 1927, p. 10, fig. 3). This photograph shows leaves that are predominantly five-lobed.

Bobone (1932), in his taxonomic study of figs, does not include leaf

forms in classifying varieties, nor does he describe the foliage of any of the 27 varieties discussed. He does state, however, that the leaves of *Ficus Carica* are described by Pereira Coutinho (1913) as petiolate, large, rough-pubescent, cordiform, three- to seven-lobed or almost entire, sinuate-dentate. Bobone refers also to Melo Leote (1900), who took into account leaf form and margin in classifying figs and who pointed out that such characters are variable; that, in fact, three-, five-, and seven-lobed leaves occur simultaneously on the same tree.

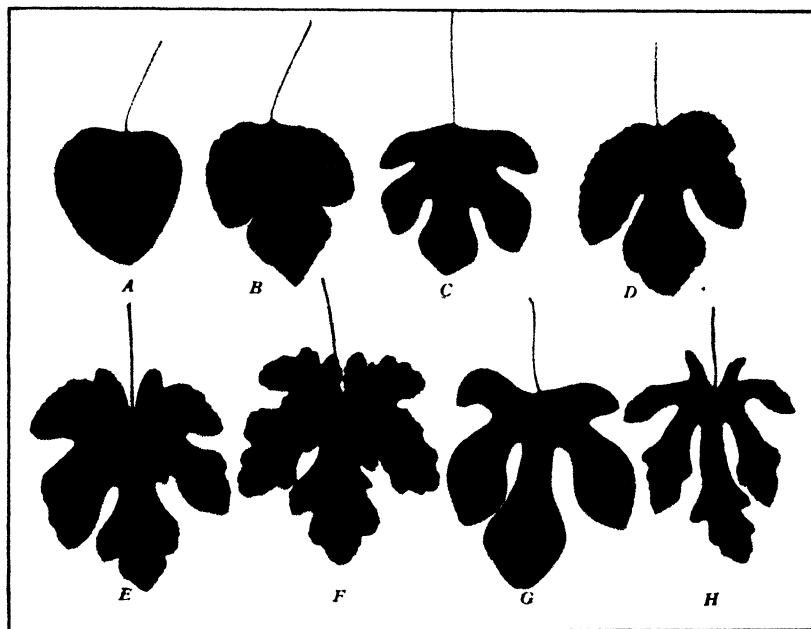


Fig. 12.—Leaf types: In A, the leaf is entire (Hamma); and in B–H the leaves are palmately lobed; B, base decurrent (Ischia); C, base truncate (Stanford capri); D, base cordate, three-lobed (Constantine); E, base cordate, five-lobed, lobes spatulate (Calimyrna); F, base calcarate, lobes latate (Mission); G, base calcarate, lobes lyrate (Turkey); H, base calcarate, lobes lineate (Brunswick).

According to Post and Dinsmore (1932–33), trees of *Ficus Carica*, both cultivated and “wild,” are common in Syria. Of the “wild” varieties, *F. Carica rupestris* Haussk. has undivided ovate to oblong leaves. Trees of *F. Carica* in California show an occasional entire leaf, but such leaves are never typical of a variety. One caprifig type of *F. palmata*, on the other hand, shows all leaves entire. Hamma also has entire leaves (fig. 12, A), and this character along with others seems to indicate that it is a variety of *F. palmata* rather than of *F. Carica*.

Fig varieties which typically have three-lobed leaves are apparently

common in Algeria, as judged by illustrations published by Mauri (1939*b*), for at least 7 of the 18 varieties illustrated show three-lobed leaves. Several of the single caprifig leaves illustrated by Mauri (1939*a*) are also three-lobed. Starnes and Monroe (1907) illustrate one leaf each of Vernissenne, Angélique, Bourgeassotte (Bourjassotte) Grise, and Versailles as three-lobed and included in the cordate type. Three-lobed leaves are the prevailing type on trees of Constantine (fig. 12, *D*) and Ischia (fig. 12, *B*) in California.

Five-lobed leaves are more or less typical of Celeste, Datte, Kadota, Pastiliere, Adriatic, and Calimyrna (fig. 12, *G*). Seven-lobed leaves or leaves with the base spurred (fig. 12, *E*, *F*, and *H*) are commonly found on trees of Jerusalem, Turkey, Brunswick, Mission, and Euscaire. On trees of most if not all these varieties, however, there are practically as many five-lobed as seven-lobed leaves, if not more—a fact which emphasizes the doubtful value of an illustration showing a single leaf as typical of a variety. In a sample of 50 leaves taken from one tree of Turkey, there were 20 five-lobed, 11 six- or seven-lobed, 12 three-lobed, and 7 almost entire leaves; in a similar Brunswick sample, 24 five-lobed, 22 six- or seven-lobed, and 4 three-lobed leaves; and in a sample of Euscaire, 18 five-lobed, 22 six- or seven-lobed, and 10 three-lobed leaves.

The following outline is suggested for use in classifying leaf types:

Leaf entire, base truncate—Hamma (fig. 12, *A*)

Leaf palmately lobed:

Base decurrent—Ischia (fig. 12, *B*)

Base truncate—Stanford capri (fig. 12, *C*)

Base cordate:

Three-lobed—Constantine (fig. 12, *D*)

Five-lobed, lobes spatulate—Calimyrna (fig. 12, *G*)

Base calcarate:

Lobes latate—Mission (fig. 12, *E*)

Lobes lyrate—Turkey (fig. 12, *F*)

Lobes lineate—Brunswick (fig. 12, *H*)

Leaf Size.—Dimensions used in determining the size of the fig leaf are as follows: width of blade, *W*; length of blade, *L*; and length of petiole, *P*. The leaf-measuring card shown in figure 13, like that suggested by Bioletti (1938) for the measurement of grape leaves, facilitates the measurement of large numbers of leaves and the computation of average figures for *W*, *L*, and *P*. Relative size can then be indicated by the product $W \times L$ and the general form by the ratio W/L .

According to Bioletti (1938, p. 270), "In leaf measurements of several hundred varieties of vinifera vines at Davis, the latter ratio [W/L] has been found always greater than 1." In leaf measurements of figs, the ratio W/L is sometimes less and sometimes greater than 1; for example:

in the Calimyrna leaf it is 0.99; in Turkey, 0.96; in Datte Quotidienne, 1.0; and in Bontard, 1.1. Leaves for measuring should be selected from normal trees and from fruiting branches, at least 50 specimens being collected from a single tree.

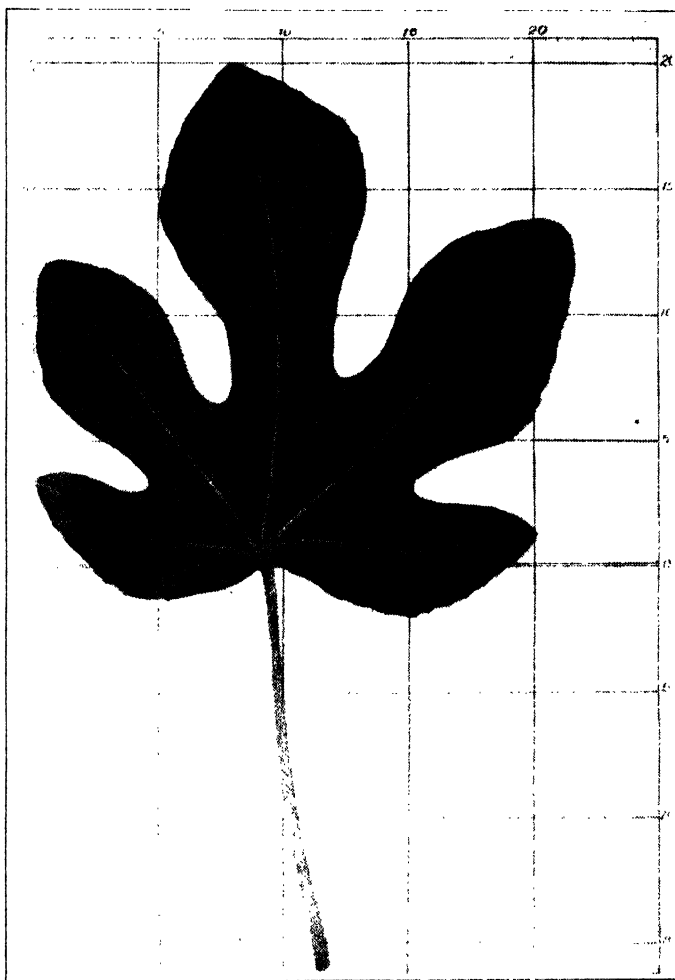


Fig. 13.—Fig leaf (lower surface, showing prominent venation) on a leaf-measuring card. Measurements, in centimeters: $L=20$; $W=21.6$; $P=16.3$; $W \times L=432$; $W/L=1.08$; $P/L=0.815$.

Size classes of fig leaves are shown in table 7. Some varieties, such as Ischia, Celeste, and Roeding No. 3, have relatively small leaves. Some like Biskra and Marabout have large or very large leaves. Some very small leaves can be found on trees of *Ficus Carica*, but none of the varie-

ties studied have leaves averaging as small as those of *F. Pseudo-Carica* (table 7) or of many seedlings of *F. palmata*.

Leaf Sinuses.—The leaf of the fig, like that of the grape, commonly has five main veins, each originating at the petiole and supplying a corresponding lobe. Between these lobes are the five sinuses—two upper, two lower, and the petiolar sinus. Leaf lobes may be wide and may overlap each other so that the sinuses are not very distinct, as in leaves of Pingo de Mel (Eisen, 1901, p. 262).

TABLE 7
SIZE CLASSES OF LEAVES

Class	Leaf area limits (W×L)	Example (Riverside)			
		Variety	Length (L)	Width (W)	Area (W×L)
	sq. cm.		cm	cm	sq. cm
Very small.....	<150	<i>Ficus Pseudo-Carica</i> (edible)	10.0	6.4	64.0
Small.....	151-250	Ischia	15.6	14.2	221.5
Medium.....	251-400	Turkey	17.6	18.2	320.3
Large.....	401-550	Calimyrna	22.0	21.8	479.6
Very large.....	>550	Marabout	25.0	24.0	600.0

The upper and lower sinuses vary considerably (fig. 12) and may be classified according to depth and form as follows:

Depth:

Shallow—Ischia, fig. 12, *B*

Medium—Mission, fig. 12, *E*

Deep—Calimyrna, fig. 12, *G*

Form:

Narrow—Ischia, fig. 12, *B*

Wide—Calimyrna, fig. 12, *G*

The petiolar sinus may be described in the following terms:

Closed—Turkey (sometimes on sucker wood)

Narrow—Turkey (on heavily pruned trees), fig. 12, *F*

Medium—Brunswick, fig. 12, *H*

Wide—Calimyrna, fig. 12, *G*

Leaf Margins.—None of the fig varieties studied have leaves with entire margins, although some leaves, like those of Martinique, are nearly entire. In leaves of Calimyrna (fig. 12, *G*), Adriatic, and Sultane, the lower margins of lobes are entire, while the upper margins are crenate. Entire leaves like those of Hamma (fig. 12, *A*) and *Ficus palmata* have crenate margins. Many varieties, Mission (fig. 12, *E*), for example, have

leaves with coarsely crenate margins. Mauri (1939b) describes the leaves of several Kabyle varieties as having margins "dentes," although in his illustrations, the teeth are rounded or crenate.

Leaf Color.—Leaves of cultivated fig varieties are predominantly bright green. Some varieties, such as Baalie and Marabout, show a distinctly lighter green foliage than others. Eisen (1901) describes Mission as having glossy leaves, lighter green than most other figs and most characteristically mottled with lighter, yellowish green. The last part of this description probably refers to the mosaicked condition common to the Mission leaf. Either mosaic spots or a rusty condition of the lower leaf surface sometimes make the color appear lighter, but these are abnormal conditions and are not characteristic of the variety. The lower side of a fig leaf is invariably of a much lighter shade of green than the upper, partly because of the numerous epidermal hairs on the lower surface.

Leaf Surface.—The five main veins of a typical fig leaf are very light green or almost white, the color contrasting sharply with the deep green of the general leaf surface. On the upper side of the leaf, the larger veins may protrude slightly or be practically level with the leaf surface. On the lower side, all the larger veins and many of the small white veinlets project somewhat above the surface, so that the fine meshes of mesophyll, about 1 mm across, can readily be seen by the unaided eye. The upper surface of most fig leaves is fairly smooth, while that of some—Panaché, Fraga, and Barnissotte, for example—is somewhat raised or bulging between the veinlets.

Leaves of Fraga, Adriatic, and Constantine have a somewhat glossy or shiny surface in comparison with the dull surface of Kadota and Calimyrna. Calimyrna leaves generally lie flat or in one plane, in contrast to many others which are undulate. Some leaves, like those of Adriatic, have a tendency to turn up at the edges and have, consequently, a slightly concave surface.

The epidermis on both the upper and the lower side of the leaf is studded with minute hairs or spicules. On the upper surface, the hairs are stiff and widely scattered, rendering it like sandpaper to the touch; on the lower surface, the hairs are numerous and soft, making this surface velvety. As pointed out by Renner (1906), there are on the lower leaf surface some capitate three- to four-celled hairs, as well as numerous unicellular hairs of various lengths. Examination of leaves of 7 fig varieties at Riverside shows that hairs on the lower surface are much more numerous and much longer than those on the upper surface. Measurements of the longest hairs are as follows: on the upper surface, 19.9 μ ; on the lower surface, 31.1 μ . Capitate hairs are scarce and almost

identical in shape and size with those on the surface of the fruit. Hairs on leaves and petioles of some horticultural forms of *Ficus Pseudo-Carica* and of *F. palmata* are so very numerous that these organs are prominently pubescent. Eisen (1901) states that the leaves of *Albo* are fairly hairy or pubescent, more so than those of most other varieties.

Texture of Leaves.—Mature leaves of *Ficus Pseudo-Carica* and of *F. palmata* are fairly thin and pliable. Leaves of *F. Carica* are comparatively thick and stiff, although among the different kinds there is considerable variation in thickness and texture. Adriatic leaves are stiff and harsh and make the harvesting of the fresh fruit more difficult than that of Kadota and Calimyrna, both of which have more pliable leaves.

TABLE 8

VARIATION IN PETIOLE IN FIG VARIETIES; AVERAGE DIAMETERS IN MILLIMETERS

Slender		Medium		Thick	
Variety	Diameter	Variety	Diameter	Variety	Diameter
Hamma.....	3.5	Turkey.....	5.0	Pastiliere.....	6.6
Ischia.....	3.8	Calimyrna.....	5.2	Sultane.....	7.1
Bontard.....	4.1	Mission.....	5.7	Euseinire.....	7.6
Constantine.....	4.2	Kadota.....	5.9	Marabout.....	7.7

Panaché, Fraga, and Pastiliere commonly have rather thick and brittle leaves.

Petiole.—The petioles (leaf stalks) are described in terms of length, thickness, surface, and color. Mauri (1939b) describes petioles as thick, thin, long, short, slender, green, or, sometimes, as tinted with rose-carmine. The terms “long,” “medium,” and “short” have little meaning unless some standard of comparison is used. Such a standard, as in the study of grapes, can be the relation of petiole length to length of midvein. Bioletti (1938) found that in grapes, the midvalue P/L ranged from 0.6 to 1.2. In figs, the highest value found for P/L was 0.75 in Marseilles, although Croisic and Marabout actually have the longest petioles, each averaging 12 cm.

Petiole length varies considerably, leaves growing in the shade having longer petioles than those exposed to the sun. Sometimes the petioles are slightly flattened, as shown in a cross section. Baalie has curved petioles with drooping leaves.

Thickness of the petiole can best be determined by actual measurement of the diameter about one-fourth inch back from the point of union with the twig, as recorded in table 8.

Color of petiole is apparently closely correlated with color of fruit

and of terminal bud. Mission, Ischia Black, Violette de Bordeaux, Precoce de Barcelone, all have black fruit, pinkish or brown terminal buds, and pinkish petioles. This correlation is also exemplified in a population of 328 chance seedlings of Marabout, another black-fruited variety which has both petioles and terminal buds pinkish. Of these seedlings, 166 showed pink terminal buds and pink petioles, 85 showed green buds and green petioles, and 77 showed intermediate-colored buds. Of the



Fig. 14.—A cystolith or stalked spherical body incrustated with successive layers of calcium carbonate, formed in an enlarged epidermal cell of the lower surface of a fig leaf. (Photomicrograph by F. M. Turrell; magnification, $\times 240$.)

last-named group, 10 seedlings showed green petioles, 61 showed pink petioles, and 6 showed intermediate-colored petioles. Roeding No. 3 and Euseaire, which show pinkish terminal buds, have green petioles. Green is the predominant color of petiole in figs that have green or yellow fruits.

Cystoliths.—Most species of such plant families as the Urticaceae, Moraceae, and Acanthaceae develop in specialized leaf cells peculiar calcified bodies termed “cystoliths,” which have been studied or described by various botanists including Kohl (1889), Renner (1906), Solereder (1908), Haberlandt (1914), and Berg (1932).

When sectioned, fig leaves commonly show among the spongy paren-

chyma cells of the lower leaf surface very much enlarged epidermal cells, each containing a peculiar stalked body covered with blunt projections. This body, or cystolith (fig. 14), is built up from the epidermal portion of the cell wall as a stalked protrusion on which are gradually deposited successive layers of calcium carbonate. The stalk itself is strongly silicified and ordinarily extends beyond the surface of the cell into a sharp nipplelike protuberance. Apparently, cystoliths are bodies of an excretory nature providing special reservoirs for the calcium carbonate that becomes superfluous in the metabolic process.

Kohl (1889) found that the lime content of the cystolith diminishes in the autumn and concluded that it was withdrawn into the stem. Berg (1932), however, examined at intervals cystoliths from green fig leaves on the tree, from leaves picked and placed in a moist chamber, and from leaves which dropped naturally. He found that cystoliths remain normally incrustated with lime so long as the leaf cells are alive and become decalcified only as the cells discolor and shrivel, when it is too late for any movement of material into the stem.

While Turgano (1926) found that cystoliths have some taxonomic significance in separating different species of *Ficus*, I am convinced that they have no value in classifying varieties of *F. Carica*. A study of 7 fig varieties at Riverside shows that cystolith cells are very widely scattered among cells of the lower leaf surface. Cystoliths which are strongly calcified are torn loose during the sectioning process, leaving only the large empty cell. In general, they are oval or almost spherical, with blunt protuberances (fig. 14). Measurements made on 24 cystoliths show the following averages: thickness of leaf, 177.2 μ ; length of cystolith cell, including the protruding nipple, 55.9 μ ; breadth of cell, 44.6 μ .

THE TREE

Tree characters which are worthy of consideration in a taxonomic study of the fig are: size, habit of growth, wood, bark, roots, burrknots, bark tubers, nodal swellings, buds, odor, crops, fruitfulness, and season.

Size of Tree.—In Europe, the fig tree does not reach the venerable age, nor does it attain the size of trunk common to the olive. It apparently succumbs more readily than many other fruit trees to root troubles, sunburn of the bark, borers, and fungi. J. L. (1890), in an account of the Tarring Fig Gardens at Sussex, England, stated, however, that the first tree at Tarring was planted by Thomas à Becket 800 years earlier and that the identical tree was still there. It was struck by lightning in 1885; the dead trunk was still standing in 1890 and was 5 feet in circumference at the base. Wright (1891–94) reported that the grand old Marseilles tree in the Tarring Gardens was 9 feet in circumference

in 1872, the trunk separating into four main limbs, each nearly 3 feet in circumference.

California and Arizona boast of several fig trees as "the largest in the world." The oldest fig tree in California is probably a Mission planted



Fig. 15.—Fig orchard in Yosemite Colony, Merced, California, in which Calimyrna trees alternate with Adriatic. The upper photograph (taken in November, 1921) shows Calimyrna on the left and Adriatic on the right. In the lower photograph (taken in December, 1939), Adriatic is on the left and Calimyrna on the right. Note the more upright and open habit of growth of the Calimyrna trees.

about 1800 by Don Valentin Higuera, alcalde of Mission San Jose. This tree is now on the William Curtner place between Warm Springs and Milpitas. The largest of which I have a record is in a group of Mission fig trees planted in 1852 on the Henry Clark place, about 6 miles northwest of Corning, California. The circumference of the trunk, 4 feet

above the ground, measures 14 feet, 1 inch. Other trees in the group have trunks from 11 feet, 4 inches to 13 feet in circumference.

Varieties differ somewhat in vigor of growth and consequently in size or circumference of trunk. An orchard planted in Yosemite Colony, near Merced, in 1918, consisted of Calimyrna and Adriatic trees (fig. 15), alternating. Measurements of 10 trees of each variety, made in February, 1940, showed that the Calimyrna trees averaged 1,052 mm in trunk circumference and the Adriatic, 1,030 mm, the smaller size of the latter being partly due to more serious frost damage to the tops.

In March, 1928, an irrigation experiment on 4 varieties of fig trees was started at the Citrus Experiment Station at Riverside. As representa-

TABLE 9
EFFECT OF IRRIGATION ON SIZE OF FIG TREES; TRUNK CIRCUMFERENCES
IN MILLIMETERS

Variety	Irrigated twice a month			Unirrigated		
	Circumference in 1930	Circumference in 1939	Per cent gain	Circumference in 1930	Circumference in 1939	Per cent gain
Mission.....	294	978	69.9	183	545	66.4
Calimyrna.....	323	865	62.6	224	598	62.8
Kadota.....	364	876	58.4	211	531	60.2
Turkey.....	282	712	60.3	179	426	57.9

tive of the growth made, trunk-circumference measurements for 1930 and for 1939 are given in table 9. These measurements show that Mission, which started next to smallest in size, was the largest tree in the irrigated row in 1939 and next to largest in the unirrigated row. The Turkey tree was smallest of the 4 varieties, partly on account of the dwarfing effect of its heavy crops.

Vigor of growth and size of tree are markedly affected by environmental conditions. The Brunswick (Magnolia) tree grown under summer rainfall conditions in Texas is vigorous and remarkably productive. The Brunswick grown in California under the usual 30-day-irrigation schedule is comparatively dwarf and unproductive.

Habit of Growth.—Fig trees have a habit of growth, or a system of branching, which is more or less characteristic of the variety. Adriatic trees are, in general, round-topped, with broad spreading branches. This is also the characteristic form of Stanford and Samson caprifig trees. Calimyrna trees (fig. 16) have a more upright habit of growth, with fewer laterals than Adriatic, and unless they are pruned properly, the branches often tend to droop badly. The Stanford Smyrna (fig. 16), on the other hand, has a more compact system of branches, with little tend-

ency to droop. Some Mission trees have a massive columnar top, while others have spreading branches, the tips of which often reach the ground and take root, and thus form new trunks. The Roeding No. 3 caprifig tree has a dense growth of slender branches, while Roeding No. 2 has willowy branches, upright in habit. Col de Signora Nigra tree has an unusually tall, upright habit of growth. Pastiliere and Sultane have gnarled stubby branches with swollen nodes. Hamma, probably a form of *Ficus palmata*, has slender willowy branches and twigs.

In 13 out of 100 seedlings of the cross Calimyrna $\times$ Maslin 148, the branches are brachytic (fig. 17). Of the cross Calimyrna $\times$ Stanford, 12 out of 115 seedlings also show brachytic growth. Brachysm, however, is



Fig. 16.—The Calimyrna fig tree, on the right, has an open habit of growth, with outer branches inclined to droop. The Stanford Smyrna, on the left, has a dense habit of growth.

not a variety character, for such a seedling would hardly be worthy of perpetuation as a variety, on account of its poor growth habit.

Hardiness.—In the fig tree, hardiness is correlated with vigor of growth, slow-growing trees such as Brunswick and Turkey usually being most hardy. Hodgson (1933) found evidence of varietal differences as to hardiness, "the apparent descending order of resistance being as follows: Brunswick, white varieties (Kadota, Calimyrna, Adriatic), Mission." Time of leafing out in spring sometimes affects the degree of frost injury in case of cold weather; thus Adriatic, which leafs out about 10 days earlier than Calimyrna, may suffer frost injury, while the latter escapes uninjured.

Wood.—Fig wood, like that of willow, is soft and of comparatively little value. Theophrastus (1916) regarded fig wood as strong when set upright and as of some value in kindling a fire. Cato (1933) suggested the use of fig wood for crosspieces after seasoning in a manure pile or under water. Noisette (1829) reported that locksmiths and gunsmiths sometimes use fig wood for rubbing and polishing, since it readily takes up oil and emery.

Tests made of wood of 4 varieties of fig,¹² show the average specific gravity to be 0.43, based on volume when green and on weight when oven dry. For comparison, the specific gravity of certain hardwoods and softwoods, as determined by Markwardt and Wilson (1935), is given here: catalpa, 0.53; elm, 0.55; ponderosa pine, 0.42; redwood, 0.40.



Fig. 17.—Seedling buds: *A, B*, showing brachytic growth; those on the other stubs show vigorous and normal growth.

Fig wood is so soft that it cuts “almost like butter,” at least pruners think so when passing from fig-tree pruning to the cutting of hardwood

¹² Specific gravity tests of fig wood were made by R. A. Cockrell, Assistant Professor of Forestry and Assistant Forester in the Experiment Station.

trees such as the olive and orange. The color is very light or almost white. Annual rings are not easily distinguishable because of the uniform color of the wood. As pointed out by Solereder (1908), the pith is homogeneous in *Ficus*. Photomicrographs of fig-wood sections (fig. 18) show

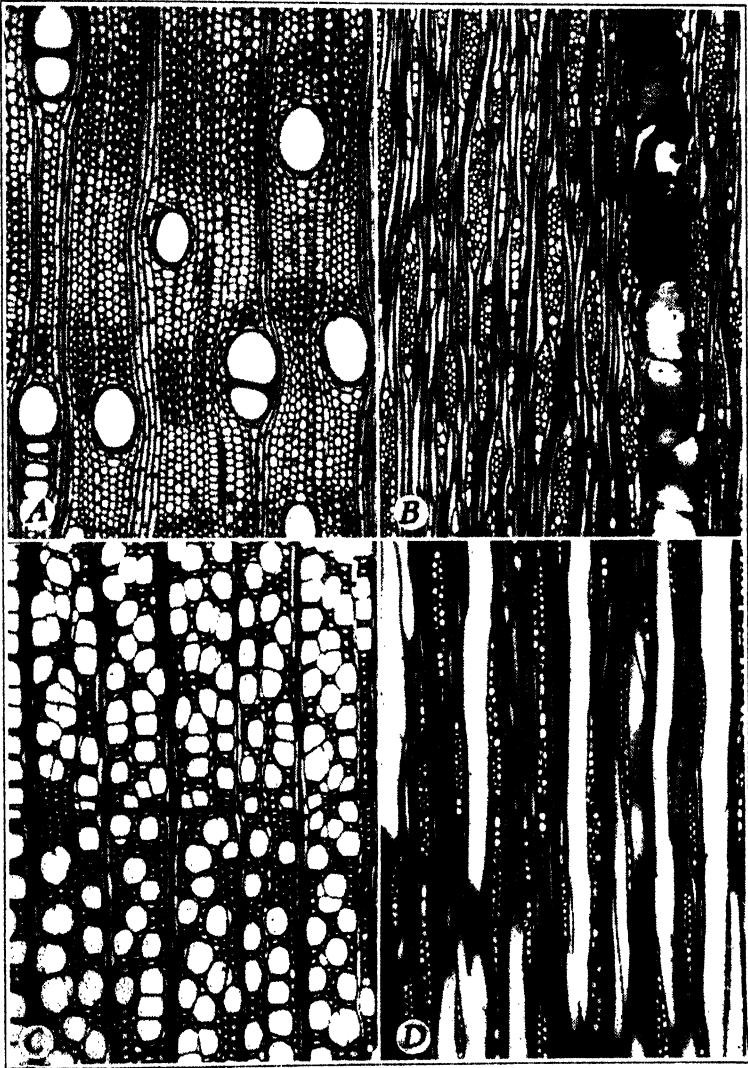


Fig. 18.—A, B, Transverse and tangential sections of fig wood (*Ficus Carica*); C, D, sections of hardwood (*Liquidambar styraciflua*). Note the comparative differences in amount of parenchyma and relative wall thickness of parenchyma and fiber cells. (Photomicrographs by R. A. Cockrell; magnification, $\times 70$.)

alternating bands of thin-walled wood parenchyma and relatively thin-walled fibers. Wood with such a preponderance of parenchyma tissue is not comparable in strength to that of a commercial hardwood, such as *Liquidambar styraciflua* L., which has thick-walled fibers (fig. 18).

Bark.—The bark of fig trees is comparatively smooth (fig. 19) and seldom fissured, as in many other trees. Varieties differ very little in



Fig. 19.—Trunk of a fig tree showing the graft union between the Mission stock and the Adriatic top and the comparatively smooth bark characteristic of most figs. Lichens are growing on the Adriatic bark.

bark characters. The bark of Samson (Markarian No. 1) caprifig is, on the trunk and older branches, characteristically fissured or corrugated. The bark of Roeding No. 2 caprifig is not smooth but scaly (fig. 20), at least on the trunk. Lenticels are conspicuous on young branches. Devaux (1900) included the fig in a long list of plants having lenticels composed of thin, flattened scales much like those of the oak. He illustrated and described hypertrophy in the fig lenticel.

Roots.—The fig tree has a system of fibrous roots which spread con-

siderable distances laterally and, in some soils, to a surprisingly great depth. Theophrastus (1916) noted that some trees, such as fig, oak, and plane, have many long roots, the fig probably having the longest of any. Traub and Stansel (1930) found in Texas that five-year-old *Magnolia* fig trees had a root spread of 50 feet, a single lateral reaching 35 feet from the main trunk. Some roots were traced in calcareous clay to a



Fig. 20.—The bark of Roeding No. 2 caprifig tree is scaly, at least on the trunk

depth of 5 feet and probably extended a couple of feet deeper. Condit (1920) studied the root systems of young fig trees on hardpan land near Fresno and found roots penetrating either the hole made by blasting or natural cracks in the hardpan. Reports made verbally by growers indicate that fig roots on lands near Fresno extend to a depth of 20 feet and probably much deeper. No published data are available on comparative root systems of the different varieties.

Burrknots.—A burrknot is a rough excrecence often present on the trunk or roots of certain trees and characteristic of some varieties. Refer-

ences to their occurrence on various forest and fruit trees and to their use in plant propagation are given by Hatton *et al.* (1926) and by C. F. Swingle (1925) ; the latter has also discussed (Swingle, 1927) burrknot formations in relation to the vascular system of the apple stem. Neither of these writers describes such excrescences on the fig tree, although Hatton *et al.* refer to the article by Wolf (1913) discussed later in this section. Swingle (1925) states that except for the bare mention of their occurrence on willow, he "has been unable to find a single sentence in American literature regarding nonpathological, dormant, stem-borne



Fig. 21.—Bark excrescences or burrknots, which develop into roots, as shown, when placed in moist soil or moss, are common on fig trees in humid climates.

roots in any plant." The account by Wolf (1913) is entitled "Abnormal Roots of Figs," and in it he refers to "several cuttings of these diseased figs." This apparently explains the omission of the fig from Swingle's (1925) account, as he was only investigating "nonpathological" roots.

Many species of the genus *Ficus*, the banyan (*F. benghalensis* L.) being a good example, produce aerial roots in profusion from the trunk and large branches. *F. Carica* does not produce aerial roots in nature but does generate root initials very profusely when branches are placed in a suitable rooting medium. It is not strange, therefore, that trees of this species exhibit these burrknots when growing under favorable conditions. Wolf (1913) found on orchard trees in Alabama "that these

processes were present also upon the trunk and larger branches, occurring for the most part upon the lower side of the limbs or on the north side of the trees." He concluded that these processes are morphologically roots which may function as roots in response to a superabundance of moisture. In California, burrknots (fig. 21) occur commonly on fig trees in humid coast climates and sparingly in dry interior districts. They are



Fig. 22.—Bark tubers commonly occur on the trunk and larger branches of the fig tree. Nodal swellings may be seen on the branch at the left.

located at random both at or near the nodes and on the internodes. Apparently, the origin of adventitious roots which appear on fig cuttings in the soil is the same as, or similar to, that of burrknots.

Bark Tubers.—The bark of the trunk and larger branches of most fig trees shows numerous excrescences or tubers (fig. 22) similar to those which have been described by Sorauer (1922) as occurring on

various other plants. It was probably these bark tubers which Theophrastus (1916) described as being characteristic of the alder, bay, fig, and other smooth-barked trees. Such tubers are formed from dormant buds whose apex dies, but whose base retains its vascular connection with the wood (fig. 23), the fibrovascular body continuing to form its own bark and new wood layers without the aid of foliage.

Tuber initials, 1 mm in diameter or smaller, can sometimes be found by carefully shaving off thin layers of bark in certain places. When first

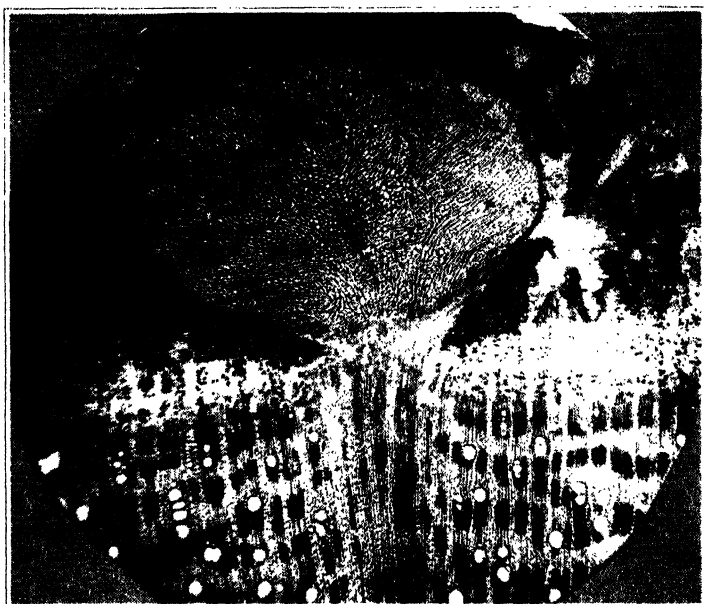


Fig. 23.—Cross section of a bark tuber, which is a dormant bud whose apex dies, but whose base retains its vascular connection with the wood, the fibrovascular body continuing to form its own bark and wood without the aid of foliage. (Photomicrograph by F. M. Turrell; magnification, $\times 15$.)

visible on bark of the fig tree, the tubers measure approximately 2 mm in diameter; some large ones measure 20 mm in diameter. They are mostly spherical, although some become elongated. No tubers have been seen on fig branches under three years old; they apparently form on trunk and branches of older trees and continue to form until trees are many years of age. They appear very commonly on the bark of nodal swellings.

Nodal Swellings.—The branches of several varieties of figs show prominent enlargements or swellings at the nodes (fig. 22). These swellings are seldom apparent during the first growing season, but gradually be-

come prominent during ensuing seasons and continue to enlarge indefinitely. They form under and on both sides of the leaf scar, gradually covering a little over half the branch circumference. They are especially prominent on Sultane and Pastiliere and are also found on trees of at least 12 varieties in a collection consisting of 162 distinct varieties. Nodal swellings are apparently of wide occurrence, for they have appeared on new growth of fig scions secured from Texas, England, and southern Russia.

The famous widespreading tree of San Pedro at Parlier, California,



Fig. 24.--Nodal swellings are unusually prominent on the trunk and branches of the famous park tree, San Pedro variety, at Parlier, California.

shows unusually prominent nodal swellings (fig. 24). Such swellings are common on old trees of Calimyrna, notably so in the William Pugh orchard at Planada, California. The fact that practically all trees in this orchard show prominent nodal swellings would seem to indicate that there is a type or strain of Calimyrna tree in which the swellings are unusually pronounced.

Buds.—The tree of *Ficus Carica* is ordinarily deciduous, the length of the dormant season depending upon local climatic conditions. During the late summer and fall, both fruit and vegetative buds form in axils of leaves and remain on the tree during the winter. Moreover, in mild climates, partly grown figs of some varieties remain on the tree and mature in the spring.

Dormant fruit buds are distinguishable from the vegetative buds by

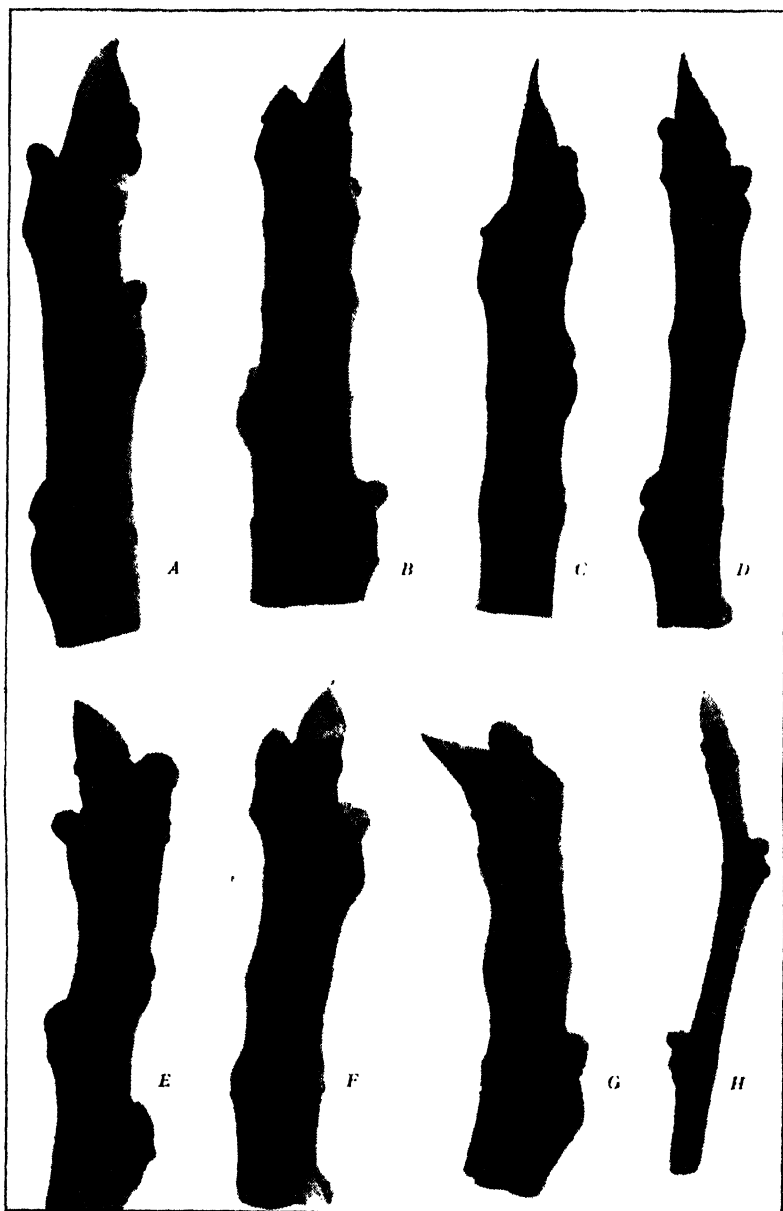


Fig. 25.—Dormant fruit buds and terminal buds of different fig varieties: *A*, Marabout; *B*, Maslin 150; *C*, Kadota; *D*, Mission. These all have conical, sharp-pointed buds. *E*, Pastiliere, and *F*, Milco, have short thick buds. The terminal bud is inclined at an angle from the center in *G*, Kearney. *H*, Hamma, has a slender twig and small plump bud.

their large size and plump, rounded appearance. The number and size of fruit buds are closely related to the vegetative growth of the tree and the size of the crop maturing in summer and fall. Caprifigs which have a very light mammoni or summer crop commonly produce an enormous number of fruit buds, which expand in the spring and mature a crop in June. Color of fruit buds is approximately that of the terminal bud.

Characters of the terminal bud, such as color, shape, and size, have some taxonomic significance. Color of bud is largely correlated with color of fruit, most green-fruited varieties having green buds and most

TABLE 10
COMPARATIVE SIZES OF TWIGS AND TERMINAL BUDS OF FIG VARIETIES*

Variety	Twig diameter	Bud		
		Diameter at base (D)	Length (L)	L/D
	mm	mm	mm	ratio
Hamma.....	5	4	7	1.7
Kadota.....	11	6	13	2.1
Kearney.....	11	7	12	1.7
Marabout.....	13	9	14	1.5
Maslin 150.....	13	6	10	1.6
Mileo.....	10	7	8	1.1
Mission.....	10	6	11	1.8
Pastiliere.....	11	7	9	1.3

* Average measurements of eight specimens of twigs and terminal buds of each variety.

dark-fruited varieties having dark-colored buds. Green color in the bud varies from bright grass green to yellowish green; dark color in the bud means any shade of pink, brick red, or violet-purple. Some varieties, such as Col de Signora Nigra and Gouraud Rouge, having dark figs show green terminal buds; and, vice versa, some with green figs, notably Genoa, have dark-colored buds. Shapes of terminal buds are, in general, conical, the tip being more or less attenuate. In some varieties, such as Pastiliere and Mileo, the bud is thick and short (fig. 25, *E* and *F*), while in others it is more conical and sharp-pointed, as in Maslin 150, Kadota, and Mission (fig. 25, *B*, *C*, and *D*). Varieties such as Marabout and Pastiliere, which have thick, stubby branches and twigs (fig. 25, *A* and *E*), generally have large thick buds. The terminal bud in Kearney (fig. 25, *G*) and in some other varieties is inclined at an angle rather than located centrally. Buds of Hamma (fig. 25, *H*) are slightly constricted at the base. Comparative measurements of twigs and terminal buds of several different varieties are given in table 10.

Odor.—Various parts of the fig tree have a more or less distinctive

odor or fragrance which one can often distinguish while driving along a road bordered by leafy fig trees. Wilder (1932, p. 338) reports that leaves of the fig tree have a delicious odor which they keep for years when dried. Tobacco companies recognize this fact and in some years obtain quantities of dried fig leaves to blend with tobacco for cigar wrappers.

As already pointed out, whole fresh figs do not have a distinctive aroma, although the pulp often has a pleasing odor which augments the eating quality. Caprifigs do, however, emit a characteristic fragrance, which apparently attracts the female blastophaga to the figs when the flowers are receptive to pollen or to oviposition. Mr. Francis Heiny of Brawley, California, named one of his seedling caprifigs "Fragrant," because of its unusually strong fragrance.

Crops.—Caprifig trees, as explained by Condit (1932), ordinarily produce three series of fruit buds each growing season. The first series of buds gives rise to the profichi or spring crop, the second series to the mammoni or summer crop, and the third series to the mamme or winter crop. In cool climates only two crops mature, while in hot desert locations as many as seven crops of caprifigs are said to develop in one year.

Trees bearing figs with long-styled flowers have the first series of buds maturing into a breba crop (in Italy called the *flori*); the second series of buds develops into the main crop (*pedagnuoli* or *forniti* of Italy). Common figs often produce a third series of buds (*cimaruoli* in Italy) which may develop and mature the same season, may be destroyed by frost, or may remain dormant during the winter and mature the following spring.

Varieties such as Vêrdal Longue, Ischia, and Partridge Eye seldom produce any breba crop, probably on account of the enervating effect of the heavy summer and fall crops. Trees of such varieties usually have some dormant fruit buds which push out in the spring but drop when still small.

Fruitfulness.—Theophrastus (1916) made the general observation that copious production of leaves on a fruit tree reduces the quantity of fruit. He mentioned the fig and grape as exceptions, however, bearing best in years of luxuriant foliage. This is apparently true of some varieties of figs, but not of others. For example, trees of Kadota, Turkey, and Brunswick, which are pruned heavily and develop strong vegetative growth, are usually very prolific of fruit; some other varieties, such as Mission, when making vigorous sucker growth, are notably unproductive.

Barron (1868) noted that "as a general rule the smallest varieties are the most prolific. Of these, White Ischia, Black Provence and Oeil de

Perdrix bear fruit as profusely as an ordinary gooseberry bush." This is characteristic of Ischia in California and, to a lesser extent, of Celeste, another small-fruited variety. Euscaire is a medium-sized black fig of excellent quality, but it is a light producer as compared to Mission. Some caprifig trees, notably one variety of *Ficus palmata*, bear more fruits than leaves, the profichi crop being such a drain upon the tree that little if any vegetative growth takes place until after this crop matures.

Season.—According to Chandler *et al.* (1937, p. 25-26),

The fig and the Oriental persimmon, *Diospyros kaki*, are examples of deciduous trees with chilling requirements so slight that they can be grown satisfactorily in the parts of California where the winters are the warmest.

It seems probable that they have at least a slight rest period, for they usually remain dormant through favorable conditions for growth in autumn and early winter. In fact, after the warmest winters in the warmest sections of southern California, they show a slightly uneven starting of buds on the trees, as they would if there was not enough chilling to break the rest period completely. They are reported to show this tendency even more in southern Florida.

The Adriatic leafs out earlier than the Calimyrna. Precoce de Barcelone is so named because of the early maturity of its fruit; it ripens several days before that of the Mission. An entire-leaf form of *Ficus palmata* starts new growth in the spring and matures its profichi crop much earlier than other varieties of caprifig. Earliness in *F. palmata* is a dominant character and is transmitted to seedlings of which it is the male parent. The four numbered Roeding caprifigs mature fruit in the following order: No. 3, No. 1, No. 2, No. 4. Stanford is a midseason caprifig variety, while Milco is late.

The fig season in California begins in the Coachella Valley the first week in May with the ripening of Turkey figs a week or 10 days before Mission figs are mature. In the San Joaquin Valley, Mission brebas mature about the second week in June and continue until early July. Very few figs are available in any district in July; but in August, Calimyrna and Mission figs from the San Joaquin Valley and Turkey figs from Coachella and Imperial valleys flood the city markets. In seasons free from severe frosts, figs continue to ripen along the southern California coast and in the Coachella and Imperial valleys until Christmas or later. Verdal Longue, which is naturally a late-season variety, can by heavy pruning be induced to produce sucker wood which fruits unusually late. Pasquale is also a late-season variety. Marabout, at Riverside, continues to mature fruit several weeks longer than Calimyrna.

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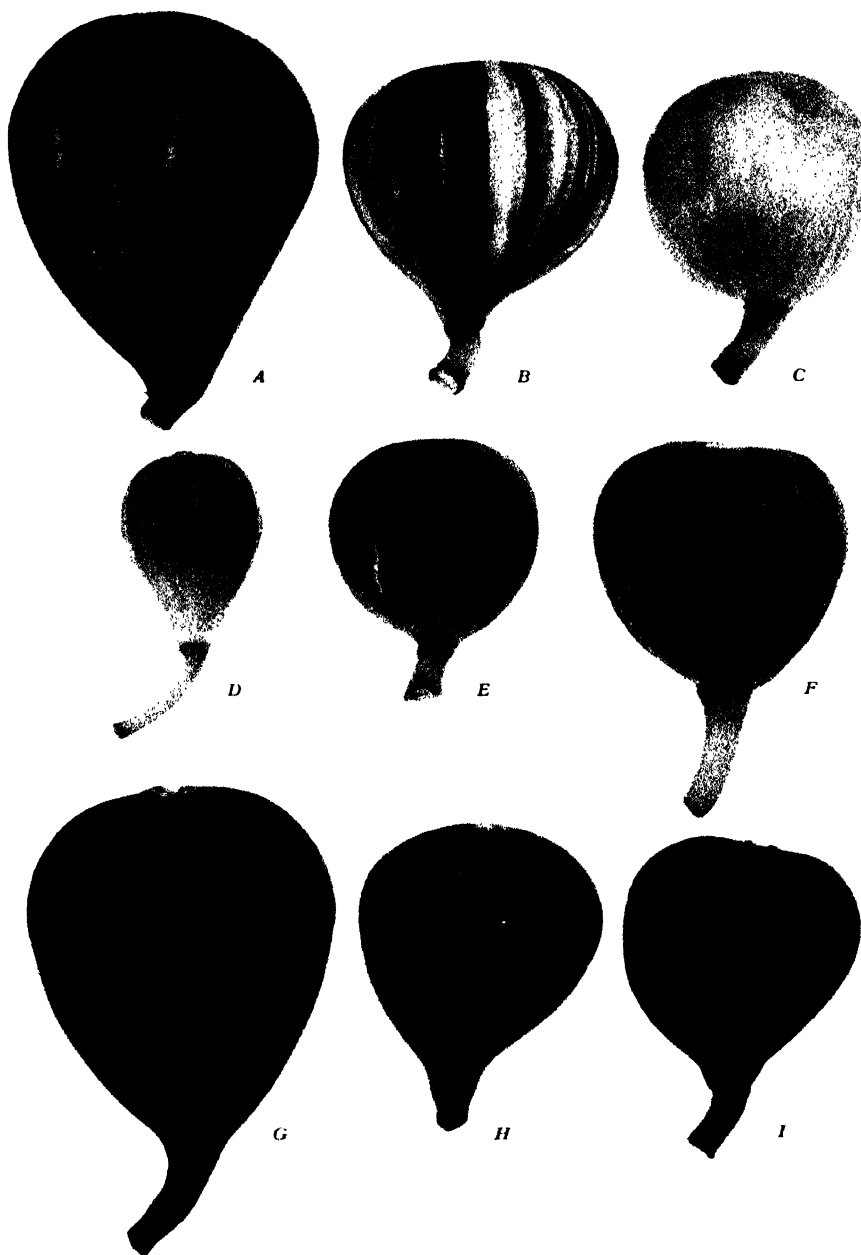


Plate 1.—Fig varieties, showing differences in external coloration: *A*, San Pietro, green; *B*, Panaché, striped green and yellow; *C*, Panaché, lemon yellow; *D*, Celeste, bronze; *E*, St. Jean Grise, violet-green; *F*, Gouraud Rouge, reddish brown; *G*, Turkey, purplish brown; *H*, Bourjassotte Grise, violet; and *I*, Ischia Black, purplish black. (Type B Kodachrome by John W. McCalley.)

CHLORATE DISTRIBUTION AND THE EFFECT OF NITRATE CONCENTRATION ON CHLORATE TOXICITY IN SOIL COLUMNS^{1,2}

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INTRODUCTION

SODIUM CHLORATE is widely used in controlling weeds. The fact that it acts most efficiently as a temporary soil sterilant (3, 5, 6)⁵ emphasizes the need for accurate knowledge of its behavior in soils.

In an attempt to evaluate the effects of soil type and rainfall on the vertical distribution of sodium chlorate in soils, Crafts (2) in 1935 performed experiments on the slow percolation of sodium chlorate solutions into columns of air-dry soil. Enough solution was allowed to drip upon the soil to just wet the entire column. The column of soil was then separated into ten equal fractions, each of which was mixed and seeded with oats. The plants were grown for 30 days. In view of the fact that in some cases the oats grew normally in soil from the bottom parts of the column, but showed high toxicity in soil from the upper parts of the column, he concluded that the chlorate had been fixed in the upper layers of soil and therefore had not reached the bottom part of the column.

In 1939, experiments reported by Crafts showed that chlorate toxicity in soils is reduced roughly in proportion to the nitrate concentration of the soil solution (4, p. 655-71). This observation suggests an alternative explanation for the low toxicities occurring in some soils near the bottom of a chlorate-treated column. The percolating chlorate solution may have

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⁵ Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

washed the nitrate out of the upper layers and concentrated it near the bottom. If so, the result would be the production of greater toxicity in the upper than in the lower part of the column, even though the concentration of chlorate were the same throughout the column. The present study was intended to determine whether this is the correct explanation or whether the chlorate is fixed in the upper layers, with consequent failure to reach the lower parts.

For this work, three of the four soils originally studied were chosen. In the original tests, Yolo clay loam had proved to be a soil in which toxicity was greatest in the upper parts of the column, whereas Stockton adobe clay showed uniform toxicity throughout the column. Fresno sandy loam⁶ was intermediate, with some reduction of toxicity near the bottom, but less than in Yolo clay loam.

METHODS

For experimental purposes, samples from the first 4 inches of the respective soils were taken from the field, air-dried, and thoroughly screened and mixed. Unless otherwise noted, two tubes of soil were set up for each test. After treatment with chlorate solution, one tube was used for the determination of toxicity, the other for chemical analysis.

The soil tubes and auxiliary apparatus used have been pictured and described in another paper (2, p. 470). Briefly, the tube is made by bending a sheet of celluloid 10 × 36 inches into a hollow cylinder about 3 inches in diameter. This is wrapped with 1/2-inch-mesh hardware cloth which is wired in place. The bottom is closed by a circle of filter paper held by a piece of hardware cloth wired to the outside of the tube. The tube, filled with soil, is secured in an upright position so that the contents of a reservoir may drip slowly upon the surface of the soil.

Table 1 gives the amount of soil used per tube for each of the three soil types represented, the volumes of sodium chlorate solution applied to each, and their respective air-dry moisture contents. The solution volumes were the amounts necessary to just moisten the columns.

In all cases 0.004 *M* sodium chlorate was used (426 p.p.m. NaClO₃). The contents of the reservoirs dripped upon the tops of the columns at a rate of about 12 drops per minute. About 36 hours was usually required to wet each column, and the tubes were allowed to stand 12 to 24 hours after the reservoirs were empty. The tubes were then opened, and each column of soil was cut into ten portions of equal length.

The portions from one of the duplicate columns were mixed individually, put into no. 2 cans, and seeded with Kanota oats. The details of this

⁶ The Fresno sandy loam used is designated on old soil maps as brown phase. Shaw (8) has classified this soil in the Dinuba series.

procedure have been described elsewhere (2, p. 463). The oats were grown in the greenhouse for 30 days, the crop in each can having been thinned to ten plants.

Then the fresh weight of tops and the average height of the plants were recorded. The fresh-weight yield was taken to be an inverse measure of toxicity, which in previous tests (2) was thought to result directly from the concentration of chlorate present. Fresh-weight yields of 0.1 gram or less are arbitrarily recorded as 0.1 gram and signify that for practical purposes there was no growth.

TABLE 1
SOIL WEIGHTS, SOLUTION VOLUMES, AND MOISTURE CONTENTS OF AIR-DRY
SOILS USED IN THE PERCOLATION TESTS

Soil	Weight of air-dry soil per tube	Volume of solution in each reservoir	Moisture content of air-dry soil, basis of oven-dry soil
	<i>kilos</i>	<i>ml</i>	<i>per cent</i>
Yolo clay loam	5 0	1,800	4.5
Stockton adobe clay	5 0	1,250	7.5
Fresno sandy loam	6 5	1,300	2 2

The portions of the other column were also mixed individually, and the moisture content of each was determined. Samples of each were extracted with water in the ratio of one part dry soil to two parts water. The soil-water mixtures were agitated continuously for about $1\frac{1}{2}$ hours and then filtered under gravity. The extracts thus obtained were analyzed for nitrate, chlorate, and chloride. The nitrate analyses were made by the Devarda method as given by the Association of Official Agricultural Chemists (1, p. 26). As shown by preliminary tests, this method was satisfactory in the presence of chlorate, whereas the phenoldisulfonic acid colorimetric method was not.⁷

Chlorate was determined by the sulfurous acid reduction method that Rosenfels has described in another paper (7). In this method the chloride content of the extract is also determined.

Single chemical analyses and moisture determinations were made; the tests were repeated on the Yolo and Stockton soils but not on Fresno sandy loam. Results typical of the data obtained are reported.

⁷ The Devarda method can be used provided the amount of Devarda's alloy taken is sufficiently in excess of that required for reduction of nitrate present. In the work here reported the amounts of chlorate present in the 20-ml aliquots used were insufficient to necessitate an increase above the customary 3 grams of Devarda's alloy. With the phenoldisulfonic acid colorimetric method, however, even small amounts of chlorate interfere seriously by forming brownish reaction products with the phenoldisulfonic acid reagent.

TABLE 2
CHEMICAL AND TOXICITY DATA AT TEN LEVELS IN COLUMNS OF SOIL TREATED WITH
0.004 M SODIUM CHLORATE

Portion	Per cent moisture, basis of dry soil	Composition of extract		Millimols per liter of indicated ion in extract			Yield of oats	
		Wet soil, grams	Water, ml	ClO ₃ ⁻	NO ₃ ⁻	Cl ⁻	Fresh weight, grams	Height, cm
Yolo clay loam								
1.....	39.4	140.0	160.0	0.75	0.00	0.00	0.2	5
2.....	39.5	140.0	160.0	0.60	0.00	0.00	0.2	5
3.....	40.4	140.0	160.0	0.60	0.00	0.00	0.1	4
4.....	41.1	140.0	160.0	0.67	0.00	0.00	0.2	6
5.....	40.6	140.0	160.0	0.67	0.00	0.00	0.2	5
6.....	39.6	140.0	160.0	0.67	0.00	0.00	0.3	5
7.....	39.3	140.0	160.0	0.90	2.00	0.00	2.1	15
8.....	41.1	140.0	160.0	0.90	5.35	0.45	4.4	23
9.....	41.9	140.0	160.0	1.02	6.10	0.45	5.1	25
10.....	39.8	140.0	160.0	1.20	14.15	1.42	5.3	26
Check.....	4.5	104.5	195.5	0.00	2.90	0.22	5.9*	28*
Yolo clay loam (leached before chlorate applied)								
1.....	40.7	140.0	160.0	0.70	0.00	0.00	0.1	2
2.....	41.5	140.0	160.0	0.69	0.00	0.00	0.1	2
3.....	40.6	140.0	160.0	0.37	0.00	0.00	0.1	2
4.....	41.6	140.0	160.0	0.58	0.00	0.00	0.1	2
5.....	42.2	140.0	160.0	0.69	0.00	0.00	0.1	2
6.....	41.3	140.0	160.0	0.70	0.00	0.00	0.1	2
7.....	44.1	140.0	160.0	0.82	0.00	0.00	0.1	2
8.....	44.5	140.0	160.0	0.78	0.00	0.00	0.1	3
9.....	45.0	140.0	160.0	0.75	0.00	0.00	0.1	3
10.....	45.4	140.0	160.0	0.67	0.00	trace	0.1	4
Check.....	4.5	104.5	195.5	0.00	2.90	0.22	5.9*	28*
Stockton adobe clay								
1.....	36.1	133.0	167.0	0.64	trace	0.00	0.1	3
2.....	34.8	133.0	167.0	0.55	trace	0.00	0.1	3
3.....	34.8	133.0	167.0	0.52	trace	0.00	0.1	3
4.....	35.2	133.0	167.0	0.45	trace	0.00	0.1	3
5.....	34.2	133.0	167.0	0.52	trace	0.00	0.1	3
6.....	33.8	133.0	167.0	0.52	0.35	0.00	0.1	3
7.....	35.0	133.0	167.0	0.67	0.35	trace	0.1	3
8.....	34.5	133.0	167.0	0.87	0.60	1.20	0.1	3
9.....	33.9	133.0	167.0	1.03	0.60	1.65	0.1	3
10.....	29.6	133.0	167.0	0.90	0.85	1.35	0.1	3
Check.....	7.5	107.5	192.5	0.00	0.36	0.42	3.5†	21†
Fresno sandy loam								
1.....	22.0	120.0	180.0	0.37	0.00	0.00	0.1	3
2.....	23.1	120.0	180.0	0.39	0.00	0.00	0.1	3
3.....	23.5	120.0	180.0	0.34	0.00	0.00	0.1	3
4.....	22.9	120.0	180.0	0.31	0.00	0.00	0.1	3
5.....	22.6	120.0	180.0	0.37	0.00	0.00	0.1	3
6.....	22.0	120.0	180.0	0.37	0.00	0.00	0.1	3
7.....	22.3	120.0	180.0	0.45	0.00	0.33	0.1	3
8.....	21.5	120.0	180.0	0.37	1.40	4.80	0.1	3
9.....	20.6	120.0	180.0	0.51	1.55	8.22	0.8	10
10.....	20.3	120.0	180.0	0.45	3.50	15.67	1.3	17
Check.....	2.2	102.2	197.8	0.00	0.76	8.81	2.4‡	22‡

* Check plants grown from December 28, 1939, to January 27, 1940; experimental plants from December 6, 1939, to January 5, 1940. Experimental plants from leached column of Yolo clay loam grown December 28, 1939, to January 27, 1940.

† Check plants grown from December 28, 1939, to January 27, 1940; experimental plants from December 20, 1939, to January 19, 1940.

‡ Both check and experimental plants grown from January 5 to February 4, 1940.

RESULTS

Table 2 gives the results of the routine tests outlined above, and also those with Yolo clay loam after it had first been thoroughly leached. The leaching experiment was intended to determine the effect on toxicity produced by removal of the nitrate before applying chlorate. To accomplish this, 1,800 ml of distilled water was first permitted to drip upon each column, which just wetted the soil. Then another 1,800 ml of distilled water was added, and the soil solution in the column was permitted to drip through the filter-paper bottom. Next, 1,800 ml of 0.004 *M* NaClO₃ was introduced. Since chlorate began to appear in the leachate before all the chlorate solution had left the reservoir, evidently the chlorate solution was not uniformly displacing the soil solution ahead of it, but was probably in part moving along the tube walls or through channels in the soil. After the 1,800 ml of chlorate solution had left the reservoir, 1,800 ml more were added to insure complete displacement of the soil solution in the column with chlorate solution. According to tests not reported, involving only one application of 1,800 ml, the chlorate concentration was very low in the bottom portions because some of the chlorate had escaped, as described above.

In all tests the ten portions of each column were numbered from 1 to 10, beginning at the top. The portion designated "check" refers to the original untreated soil. In making extracts of the check soils, allowance was made for the air-dry moisture content, and enough water was added to give a 1:2 extract. In the ten portions of wet soil taken from the tubes the exact moisture content was not known definitely ahead of time, and each portion was extracted alike without allowance for small variations in moisture content. The approximate moisture content was of course known from the weight of soil and the volume of solution in each tube.

Each yield figure reported for the check samples is the mean of two determinations, two cans of each soil being seeded.

DISCUSSION

Clearly, according to table 2, the concentration of chlorate is not lower in the bottom portions of any column than in the top. The decrease in toxicity noted was probably caused by the downward movement of nitrate. This conclusion is further supported by the fact that in Stockton adobe clay, a soil very low in nitrate, toxicity does not decrease in the lower portions. In the tenth portion in this soil the nitrate concentration was only 0.85 millimols per liter of the extract. This quantity probably included traces of nitrogen derived from some organic constituent which underwent reduction during the Devarda distillation. Furthermore, the

preliminary removal of nitrate by leaching eliminated the decrease in toxicity in Yolo clay loam, so altering the behavior of this soil that it resembled Stockton adobe clay, a soil in which fixation had never been suspected.

The data for chloride emphasize the concentration of soluble salts in the lower portions. In Fresno sandy loam the concentration of chloride in the tenth portion was more than 0.5 per cent expressed on the basis of the soil solution at a soil moisture content of 20 per cent. The plants growing in this culture appeared to suffer from excess salt, and the yield was undoubtedly reduced by the salt concentration.

Calculations made on the data of table 2 show that all the chlorate applied remained in solution because a summation of the chlorate present in the ten fractions equals that applied. In making these calculations one assumption was necessary—namely, that each portion of a given column contains one tenth of the total amount of oven-dry soil of the column. This assumption is incorrect to the extent to which settling and lack of uniformity of packing may have caused differences in density within the soil mass. To illustrate, the calculations for the first portion of the unleached Yolo clay loam column were as follows:

The moisture content was 39.4 per cent on the basis of oven-dry soil. The amount of wet soil extracted was 140 grams. The amount of water in the wet soil, therefore, was 39.6 ml. To this was added 160 ml of distilled water, making a total of 199.6 ml of water. Since the concentration of chlorate in the extract was found by analysis to be 0.75 millimols per liter, the total amount of chlorate in this amount of soil was 0.15 millimols. The amount of oven-dry soil with which this was associated was 100.4 grams. Each portion was assumed to be one tenth of 5,000 grams of air-dry soil which contained 4.5 per cent water, expressed on the oven-dry basis, which is 478.5 grams of oven-dry soil. This quantity should have contained 0.71 millimols of chlorate which could be dissolved in water. The total quantity of chlorate found in all ten portions was 7.66 millimols for Yolo clay loam, and the amount applied (1,800 ml of 0.004 *M*) was 7.20. The apparent recovery, therefore, was 106 per cent. With Fresno sandy loam the recovery was 99 per cent. With Stockton adobe clay the calculation was upset because about half of the last portion was not wet by the percolating solution; and the dry soil was discarded before making the extract. Again, nevertheless, it was evident that all the chlorate applied had appeared in solution.

Besides showing that chlorate is not fixed by the soil, the data for unleached soil (table 2) show a higher concentration of chlorate in the bottom four portions of all three soils than in the top six. This is not the case with the leached soil. This fact suggests water adsorption, a phenomenon

observed by others and termed negative adsorption.⁸ To check this point the following tests were made with Yolo clay loam:

Two columns of the soil were set up as before, one air-dry with 4.5 per cent moisture, dry basis, the other oven-dry. Sodium chlorate solution, approximately 0.004 *M*, was percolated through each column and permitted to continue on through the filter-paper bottom. Two successive 50-ml portions of each percolate were collected and then a larger third portion was collected overnight. This third portion amounted to 180 ml for the oven-dry column and to 360 ml for the air-dry soil. The six samples thus obtained and a sample of the original sodium chlorate solution were each analyzed in duplicate for chlorate. Precautions were taken to minimize evaporation during the test. The original chlorate solution proved to have a chlorate ion concentration of 4.2 millimols per liter. The first 50 ml of percolate from the oven-dry column contained 12.6 millimols per liter of chlorate; the second 50 ml, 10.0 millimols per liter; and the third portion, 7.7. The first 50 ml from the air-dry column contained 5.9; the second 50 ml, 5.9; and the third portion, 5.2. There is no doubt that the chlorate concentration was greatly increased by passage through the column of oven-dry soil and somewhat so in passing through the air-dried soil.

Another test of water adsorption was also performed. In this experiment 95 grams of oven-dry soil was mixed with 75 ml of the sodium chlorate solution and the mixture was shaken several times and let stand 24 hours. The solution was then filtered off and analyzed. The chlorate ion concentration in the filtrate was 4.6 millimols per liter, whereas in the original solution it had been 4.2 millimols per liter, as before. Sufficient filtrate was obtained for only a single analysis. The test was repeated, however, with the same result—namely, the concentration of the chlorate solution was increased approximately 10 per cent by contact with the soil. The test was also repeated using air-dry soil. In this case the increase was of the order of 3 per cent in the one trial made.

Both water adsorption and the greater effectiveness of oven-dry than of air-dry soil in causing water adsorption are strikingly demonstrated by the percolation tests. In these the solution continued to invade dry soil as it passed down the column, and presumably became increasingly concentrated as it moved downward.

In view of the foregoing results, it is reasonable to expect that differential toxicity, similar to that found with Yolo clay loam, will be encountered in the use of sodium chlorate in the control of weeds on soils that

⁸ Positive adsorption is the retention of solute molecules by the soil and results in a decrease in concentration of the leachate over that of the applied solution. Negative adsorption in the above usage is the retention of water by the soil and results in an increase in solute concentration of the leachate.

contain considerable nitrate. With soils low in nitrate, the effect is likely to be reasonably uniform throughout the depth penetrated by the chlorate. The practical expedient is to increase the chlorate dosage on nitrate-containing soils.

The toxicity of the herbicide might be less altered if the application were made in the fall when absorption by plants had reduced the nitrate concentration of the soil, but if the soil temperature is still high, decomposition of the chlorate might more than offset the effect of reduced nitrate content of the soil. In summer-fallowed soils, peat, or other soils high in nitrate or other salts, the killing of deep-rooted perennials with chlorate may become impractical, in which case clean cultivation, flooding, crop competition, or some other chemical method should be used.

SUMMARY

When sodium chlorate slowly percolates through a column of soil, some of the nitrate of the soil will be washed down to the lower levels. Since concentrating the nitrate reduces the toxicity of chlorate, the killing effect on deep-rooted plants may not be so great as it is near the surface, even though the chlorate concentration is uniform throughout the depth penetrated.

In soils originally containing little or no nitrate, a reduced toxicity is not observed in the lower levels. Similarly, preliminary removal of nitrate by leaching tends to overcome inequalities in chlorate toxicity resulting from differences in nitrate distribution.

Water adsorption was clearly demonstrated in Yolo clay loam, and was apparently manifested also by the other two soils studied.

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**MOVEMENT OF
CARBON DISULFIDE VAPOR IN SOILS**

R. M. HAGAN

MOVEMENT OF CARBON DISULFIDE VAPOR IN SOILS^{1,2}

R. M. HAGAN³

INTRODUCTION

THIS INVESTIGATION was undertaken to establish quantitatively the relation between each of several soil factors and the movement of carbon disulfide (bisulfide) through the soil. A method has been devised for measuring the movement of vapor through the soil under a constant total pressure and under carefully controlled soil conditions. Though designed for this particular problem, the general method and basis of attack on gaseous movement in soils may prove useful in general studies on soil aeration and soil structure.

This paper considers the mechanics of the method and the mathematical expression for gaseous flow⁴ in soils. It presents samples of data concerning the effect of soil factors on the measured flows of vapor. Complete data, with detailed discussion of the rôle of each soil factor, can more suitably be presented in a separate paper.

Success in using CS₂ for weed and fungus control depends upon the movement of this vapor through the soil and upon the prevention of its escape from the soil surface during and immediately after treatment. For successful field application, therefore, one should know how each soil factor—porosity, texture, degree of compaction, moisture content, and temperature—affects CS₂ vapor movement in and out of the soil. This laboratory program, the first part of which is herein reported, was planned to provide such knowledge.

With a proper background of basic facts derived from laboratory studies, the worker in the field should be able to plan more reliable experiments and perform them more efficiently, and thus arrive at generalized interpretations having wide-scale application. The ultimate purpose is to provide recommendations for commercial application of CS₂ in weed control that will insure success at a minimum cost.

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² This investigation was inaugurated and directed by the Division of Botany, College of Agriculture, under their weed control project. The work was supported by funds contributed to the Agricultural Experiment Station by the Wheeler, Reynolds, and Stauffer Chemical Company.

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⁴ In this paper the words "flow" and "movement" are used interchangeably to express the transfer of vapor from one point to another, with no attempt to recognize the possible differences in their physical meanings.

FIELD USE OF CARBON DISULFIDE

Carbon disulfide shows considerable promise as a herbicide for controlling deep-rooted perennials such as morning-glory (*Convolvulus arvensis*) and for treating oak root fungus (*Armillaria mellea*). That CS_2 or its decomposition products (SO_2 , SO_3 , and H_2S) are highly toxic to plant life is widely known.

When CS_2 is introduced below the surface as a liquid, it rapidly volatilizes and diffuses through the soil as a vapor. In treatment of morning-glory, for example, the area is laid out into squares, a small hole made in the soil at the corners of the squares with a prod, a given dose of CS_2 released at the bottom of each hole, and the hole closed by tamping. Large-scale applications are also made with an adapted subsoiler equipped with CS_2 supply lines running down the back edges of the blade standards. Commercial treatments on morning-glory have, in general, been very promising; but satisfactory kills have not always been obtained. The failures are caused, apparently, by the inability of the CS_2 to contact the roots with a toxic concentration for a sufficient time under the conditions of the treatment.

HISTORICAL INTRODUCTION AND STATEMENT OF THE PROBLEM

The movement of gases through soils has been little studied. Much of the published work has dealt with soil respiration and has presented generalized statements on soil aeration as related to plant growth. Of the work on the movement of gases through the soil, a large part has been carried out on systems of glass beads, sand, and the like, because of the complex interrelations involved in studying gaseous permeability of soils. Slichter (1897-98),⁵ who made a thorough contribution to the theoretical knowledge of pore space in artificial systems and in soils, derived an equation for liquid and gaseous flow involving Poiseuille's law. King (1897-98), testing Slichter's equations, found them applicable to several materials. Green and Ampt (1911, 1912), working with artificial systems and with soils, developed an expression of gaseous flow also based on Poiseuille's law. Furnas (1929) experimented extensively with systems involving high-pressure gradients. Buehrer (1932) used the movement of air through the soil to characterize soil structure. Muskat and Botset (1931) proved the validity of Darcy's law (1856) for gaseous flow in sands in response to a total-pressure gradient. Fancher, Lewis, and Barnes (1933), in a very extensive work, also expressed in terms of Darcy's law the

⁵ See "Literature Cited" at the end of this paper for complete data on citations, which are referred to in the text by author and date of publication.

gaseous flows observed. Muskat and Botset, with their co-workers Wyckoff and Meres, have done much work on gaseous movement in relation to oil production since the publication of their paper in 1931.

Although all these workers have made valuable contributions, their deductions do not necessarily apply to soil aeration and soil fumigation, for they have been concerned with gaseous movement in response to a *total-pressure* gradient. In the particular problem for which the work reported here was done, however, and in soil-aeration studies as a whole, we are concerned with gaseous movement in response to a *partial-pressure* gradient rather than a *total-pressure* gradient. Only for a brief period after a change in the barometric pressure or a sudden cooling or heating of the soil surface does the *total pressure* have unequal values at various points in the soil. In normal soil the gaseous phase throughout is at a constant pressure. The movements of CO_2 , O_2 , and the other gases normally present, and the movement of the fumigants introduced, all result from differences in the concentrations or *partial pressures* of the particular gas from point to point.

Buckingham (1904) carried on experiments at constant pressure, measuring gaseous movement through a thin soil layer in response to a partial-pressure gradient of the gases. He stated his results in terms of a calculated diffusion coefficient, relating the observed flows to the porosity of the soil. Smith and Brown (1933) studied the diffusion of CO_2 through soils and, using the well-known diffusion law, likewise expressed their results by use of the diffusion constant. Since, however, they were troubled with CO_2 production by the soil during their period of measurement, their results are in doubt. More recently Higgins and Pollard (1937) have reported on the distribution of CS_2 vapor through soils in large containers after the injection of the CS_2 at a central point.

This paper deals in part with the development of suitable apparatus for studying gaseous movement in soils under a partial-pressure gradient with the total pressure constant.⁶ The use of the apparatus for evaluating the effect of each soil factor on the permeability of soil to gaseous movement under a partial-pressure gradient is indicated.

The measurement of gaseous flows at different temperatures has made it possible to show that the normal diffusion law is not followed in soils even under partial-pressure gradients. The data collected have allowed the formulation of an empirical equation, shown to hold accurately over

⁶ Since this paper was prepared, there have appeared two articles by H. L. Penman of Rothamsted Experiment Station in which he describes an apparatus somewhat similar to the one devised for this investigation and draws a number of conclusions that are in substantial agreement with the results obtained by the present writer. (Penman, H. L. Gas and vapour movements in the soil. I. The diffusion of vapours through porous solids. II. The diffusion of carbon dioxide through porous solids. Jour. Agr. Sci. 30:437-62, 570-81. 1940.)

the range of the experimental measurements. The relation of this empirical expression to the established laws of flow is discussed in a later section.

GENERAL METHOD USED FOR GAS-FLOW MEASUREMENTS

The handling of CS_2 vapor and the measuring of its movement involves many experimental difficulties. Much time was consumed in developing suitable apparatus, which, however, when completed, proved adequate for measuring even small flows of CS_2 .

The apparatus (figs. 1 and 2) consists of a tube containing the soil to be analyzed, a shallow dish sealed to the lower end of the soil tube into which the liquid CS_2 is measured, and an "air-sweeper" attached to the upper end of the soil tube. The CS_2 is vaporized in the shallow dish; and the vapors, moving upward through the soil and rising from its upper surface, are collected by the air-sweeper and carried into absorber columns where the amount of CS_2 may be chemically determined. The whole apparatus is housed in an insulated room provided with heating and cooling equipment so that the temperature may be controlled to $\pm 0.25^\circ \text{C}$ and over a range of temperatures from about 5° to 45° . The partial-pressure gradient of the CS_2 is controlled by carrying out the measurements at various temperatures.

Air-dry soils are packed into tubes with a compactor machine to a known compaction (apparent density value) and at a definite moisture content. Soils on which runs will be made at a moisture content near the field capacity are packed as air-dry soil with the compactor, irrigated, and allowed to stand until the moisture has distributed relatively uniformly. Soils to be run at intermediate moisture contents are packed by hand in small increments, each increment being wetted with the calculated amount of moisture by means of an atomizer.

The ability of the CS_2 vapor to move through these soils is then determined by measuring the amount of CS_2 collected in unit time by the absorber columns when the rate of flow has reached a "steady state," a condition to be described later.

The general method possesses several advantages for soil investigations. The flows measured take place in response to partial-pressure gradients of the sort that occur in normal soil. The system of sweeping the escaping gas into absorbers provides an easily obtained and continuous record of the outflow. The chemical determination of the gas and its expression on a mass basis eliminates correction of the flow for the pressure at time of measurement. The use in general soil-permeability and soil-structure studies of a gas like CS_2 , which does not occur in soils nor alters the soil structure, eliminates the complexities introduced by gases

like CO_2 , which are affected by biological activity in the soil. The difficulties experienced by Smith and Brown (1933) in interpreting their results with CO_2 have thus been avoided in the present studies.

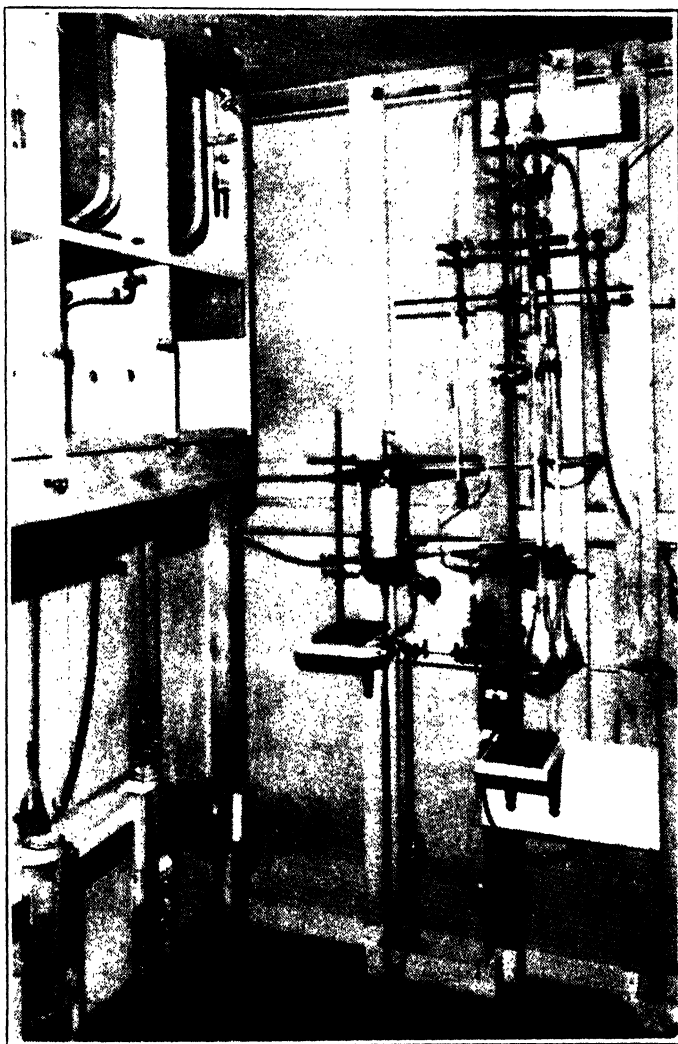


Fig. 1.--General view of the apparatus.

DESCRIPTION OF APPARATUS AND MANNER OF OPERATION

Apparatus required to measure CS_2 vapor flow through soils under a given set of conditions is necessarily complicated. A detailed description follows, with an explanation of the operation of the various units. Tem-

perature, an important factor in CS_2 flow, requires careful regulation. The following description does not include temperature control, since all the equipment is housed in a constant-temperature room.

The relation of the various units comprising the apparatus is shown in the schematic diagram of figure 2. There are three parts: the soil tube with the volatilizing dish and sweeper, the absorption device with provision for washing out with alcohol, and the suction apparatus with means to record the volume of air drawn through the sweeper.

Volatilizing-Dish Unit.—Carbon disulfide is contained in a supply tank which, for safety, is mounted outside the building. Flow from the tank is controlled by the master valve.

To fill the volatilizing dish the three-way stopcock is opened and the mercury leveling bulb lowered, drawing liquid CS_2 into the burette. This stopcock is closed to the supply line and opened to the volatilizing dish, into which the CS_2 is loaded slowly by raising the mercury bulb.

The liquid CS_2 , vaporizing, moves up through the soil into the sweeper, where an air stream carries it to the absorbers.

Absorber Unit.—Air plus CS_2 moves down into absorber flasks containing saturated alcoholic KOH. (See section on the chemistry involved in the analysis.)

Suction, applied at the top of the absorber columns, first draws the alcoholic KOH up into the glass beads. When the tip of the stem is freed, air plus CS_2 begins to bubble up. The CS_2 reacts with and is removed by the alcoholic KOH, while the air continues out the top.

The two absorber columns, *A* and *B*, form a parallel system. By operating stopcock *a* and stopcock *c*, which control the suction, one can cause the CS_2 -laden air from the sweeper to flow into either absorber *A* or *B*. In the diagram of figure 2 absorber *A* is receiving the air, while *B* is being drained and washed down with alcohol. This double absorption unit allows the air from the sweeper to be continuously analyzed.

The alcohol burette and stopcocks *e* and *f* allow for alternate washing down with alcohol and blowing out with compressed air.

The alcoholic KOH plus the CS_2 absorbed and the alcohol washings collect in the flask, which is then removed, stoppered, and later titrated.

Water-Suction Unit.—To produce the suction causing air flow through the sweeper, a special adaptation has been made of the Mariotte flask as used by Moore (1939). Water flows out of the suction bottles, causing air to be drawn into the container and to collect over the water.

The rate at which water may flow through an orifice depends on the size of that orifice and the head of water above it. If one were simply to draw air into a bottle as the water ran out, the rate at which air would be taken would decrease as the bottle emptied. To provide for a steady flow

of air, the Mariotte principle is used to give a constant head of water over the orifice in the siphon bottle regardless of the level in the suction bottle. When the water level drops in the "constant level chamber," the lower end of the flared tube is freed, the water meniscus breaks, and air is ad-

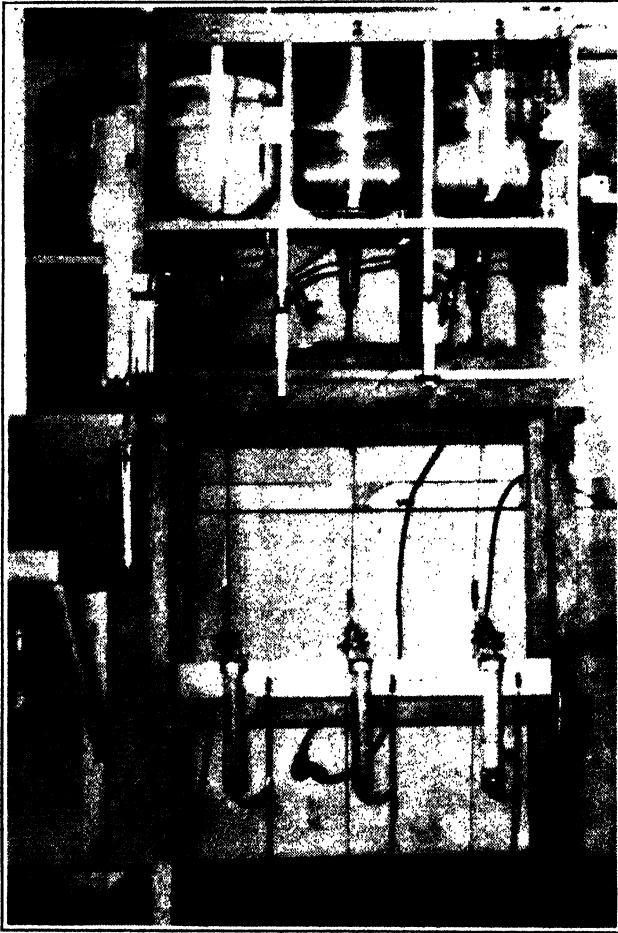


Fig. 3.—Water-suction unit. For description, see the text.

mitted to the bottle, raising the water level in the chamber until the end of the flared tube is again immersed and the air supply cut off. This cycle continuously repeated would cause periodic surges of air through the system. Because the air stream must be steady, not periodic, a section of 1-mm glass capillary tubing is interposed. The resistance to flow through

this tube is adjusted so as to minimize the effect of the pulsations resulting in a steady suction at the top of the absorber columns.

It is also necessary to know the volume of air drawn over the soil in the sweeper during a given period. This is determined by measuring the rate of water outflow from the suction bottles. Because of the inaccuracy in reading small volume changes in a large supply bottle, the water flows from the orifice into a siphon bottle, which automatically empties as it becomes filled. The number of times the siphon bottle has emptied is recorded on a scale on the suction bottle.

Figure 3 shows the water-suction apparatus. In the upper part of the rack are the suction bottles, to which are attached the "constant-level chambers." At the bottom are the siphon bottles. The manometers below and to the left of each suction bottle register the negative pressure over the water. When a suction bottle becomes empty, the suction line from the apparatus is transferred to an adjacent bottle by operation of stop-cocks, so that a continuous air stream may be maintained over long periods.

Figure 1 indicates the actual arrangement of the apparatus, with the water-suction bottles on the left, the soil tube with CS₂ burette and loading bulb in the center, and absorber columns on the right. Figure 4 shows the volatilizing dish, the soil tube, and the sweeper in greater detail.

The volatilizing dish is made of copper to provide for maximum heat conduction from the outside air to replace that required to vaporize the CS₂. The bottom is dome-shaped, with the supply tube at the low point to allow the liquid CS₂ to be drained away at the end of a run and thus to make possible a check on the quantity of CS₂ that has moved up into and through the soil column. A capillary vent keeps the pressure in the volatilizing dish equal to atmospheric pressure.

The soil tube rests in a U-shaped trough with liquid mercury as a seal. The soil is retained by an 80-mesh screen fastened into a detachable collar that fits the bottom of the soil tube. Figure 4 shows two thermometers fitted into the side of the tube and held by metal support sleeves inclined at a small angle above horizontal. Only a few tubes were equipped thus, for it was found that temperature fluctuations of $\pm 0.25^{\circ}\text{C}$ in the control room caused no perceptible variation of the thermometers in the soil.

Careful checks were made on the following possible sources of difficulty. The basic assumption made in the measurements requires that an atmosphere saturated with CS₂ be maintained under the soil column at all times during runs and at all temperatures. That this assumption is valid is indicated by tests showing that the rate of flow through the soil column was not affected by a change in shape of the volatilizing dish or by removal of all but a few cubic centimeters of the liquid CS₂. Further, it had

to be possible to load the volatilizing dish with the highly volatile CS_2 without increasing the total pressure on the lower face of the soil column. By introducing the CS_2 slowly, it was possible to meet this requirement, as indicated by the lack of a detectable reading in the arms of a carefully

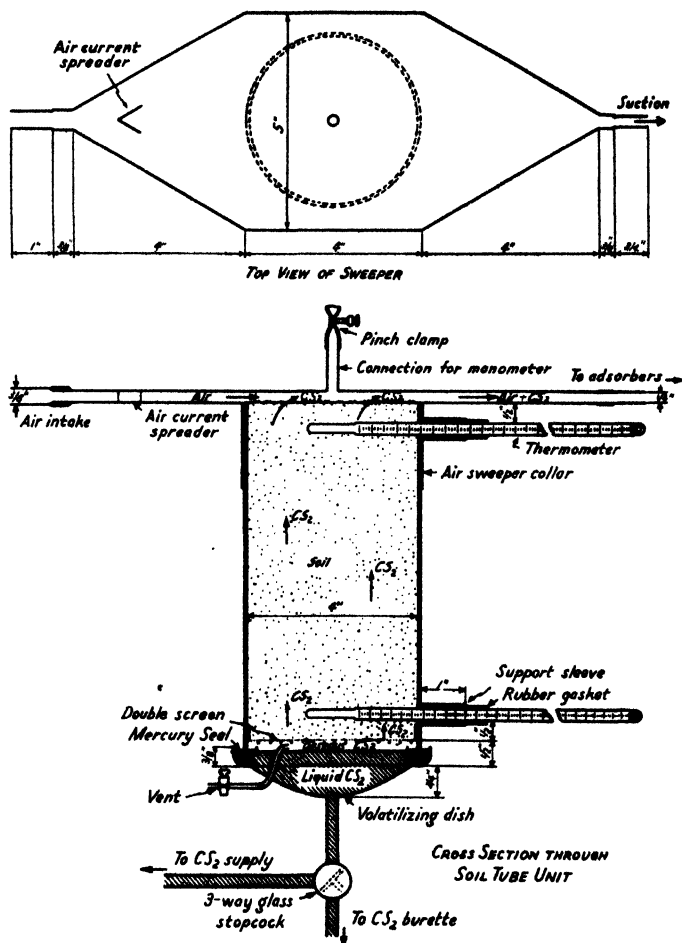


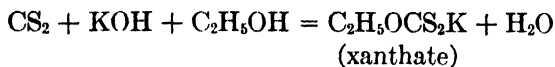
Fig. 4.—Soil tube, volatilizing dish, and sweeper. For description, see the text.

prepared water manometer during the loading of the CS_2 . The rate of air flow over the soil had to be accurately controlled and measured, for it affected the rate of flow of CS_2 from the soil by changing the partial pressure of CS_2 in the sweeper. The air-flow rate remained surprisingly con-

stant through a wide range of temperatures. In one case the extreme values for the air-flow rate were 60.8 to 61.7 cc per minute over a temperature range of 10° to 45° C.

ANALYSIS FOR CARBON DISULFIDE

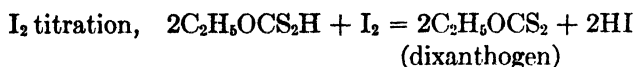
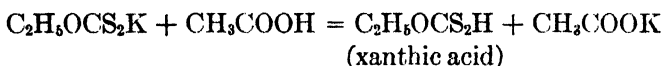
The flasks attached to the absorber columns contain a saturated solution of KOH in 95 per cent ethyl alcohol (approximately 30 gm KOH per 100 cc alcohol). The CS₂ is removed from the air stream as it bubbles up through the columns by the following reaction, resulting in the formation of a soluble xanthate:



The C₂H₅OH and KOH do not react until the CS₂ is introduced. To make this reaction go to completion, no water should be present, and none should be added until titration in order to avoid possible decomposition of the xanthate on standing, through a reversal of the reaction.

From this point on, the procedure involves routine chemical analysis following the techniques described by Fleming and Baker (1935) and Matuszak (1932). The sample is diluted with H₂O, neutralized to the phenolphthalein end point with glacial acetic acid, and then titrated with standard I₂ solution, using a starch indicator. The reactions are these:

neutralization,



During the titration the dixanthogen forms a milky emulsion that conveniently serves as a white background for easy detection of the blue-colored starch end point.

DEFINITION OF STEADY-STATE CONDITION

All values for the flow of CS₂ vapor and the soil permeability are based on "steady-state conditions," as is customary in such studies. For a period immediately following the introduction of CS₂ into the volatilizing dish, the rate at which CS₂ left the soil surface increased with time and gradually approached a steady value. At the same time as the CS₂ was introduced into the volatilizing dish, the air-sweeping and collection of samples was started. Thereafter, samples were taken at one-half hour intervals. The data for a typical run appear in table 1.

Curves plotted from such data form the basis of our definition of "steady-state" flow. Flow is considered to have attained steady state when the measured flow rate remains relatively constant with time.

The time required for reaching steady state depends on the length of the soil column. Although complete flow curves from zero time to steady state were not made in the later comparative studies, texture, and espe-

TABLE 1
RATE OF CS₂ VAPOR FLOW AS A FUNCTION OF ELAPSED TIME FOLLOWING
INTRODUCTION OF CS₂ INTO THE VOLATILIZING DISH*

Time interval	Fine sand; length of soil column, 10.65 cm	Fine sand; length of soil column, 19.95 cm	Clay loam; length of soil column, 21.20 cm
<i>hours</i>	<i>mg/min.†</i>	<i>mg/min.†</i>	<i>mg/min.†</i>
0 - ½.....	2.28	0.86	0.03
½-1.....	7.75	1.31	0.04
1 - 1½.....	—	—	3.19
1½-2.....	—	—	—
2 - 2½.....	8.30	2.74	—
2½-3.....	8.95	3.71	—
3 - 3½.....	9.14	3.76	4.72
3½-4.....	—	—	5.06
4 - 4½.....	9.27	3.67	—
4½-5.....	8.72	4.25	5.26
5 - 5½.....	9.21	4.00	5.35
5½-6.....	—	—	5.47
6 - 6½.....	9.05	4.12	5.43
6½-7.....	9.31	4.06	5.36
7 - 7½.....	9.05	4.09	5.45
7½-8.....	9.16	4.12	5.46
8 - 8½.....	9.16	4.11	5.35
8½-9.....	...	...	5.54

* The rates of CS₂ vapor flow entered in the table as mg./min. refer to the mean rate of movement of the CS₂ vapor through the soil during the time interval shown.

† Dashes indicate cases where readings were not taken in the half-hour interval; the first value set below the dash gives the mean rate calculated for the longer time interval.

cially moisture content, seemed to influence the time required for reaching steady state. In every case, soils with a high moisture content attained steady state before the drier soils.

PHYSICAL BASIS OF MEASUREMENTS AND DEVELOPMENT OF FLOW EQUATION

To express quantitatively the results of studies on flow of gases and vapors through soils, a mathematical formulation of the relations of the several measurable factors is needed. The ability of a uniform porous medium to conduct a fluid flowing with viscous motion is generally called its permeability. What is wanted, then, is an expression for the permeability of the soil under a given set of conditions, together with a mathe-

mathematical relation that will permit evaluation of the change in permeability produced by variation of one given factor.

As has been pointed out in a previous section, we are here concerned with gaseous flow in response to a partial-pressure gradient, the total pressure throughout the system being constant. Flow under these conditions is commonly called diffusion. Diffusion studies have been made largely in a system where the two components, at first held apart, are subsequently allowed to mix in the absence of any barrier between them. This free diffusion finds mathematical expression in the well-established kinetic-theory equation:

$$\frac{N}{At} = D_f \frac{(dP)}{(dL)} \quad 1$$

where N is the number of molecules diffusing, expressible in mass or volume units, through a cross-sectional area A in time t , dP/dL is the rate of change of the partial pressure of the constituent in the direction of diffusional flow, and D_f is the diffusion coefficient. In soils, however, we are dealing not with free diffusion, but with diffusion through a porous material.

Now the question arises whether the law of diffusion as given by equation 1 can apply to the movement of gases through soil under a partial-pressure gradient. Gaseous flow in soils under these conditions has been measured by Buckingham (1904) and by Smith and Brown (1933). The former has expressed his measured flows in terms of a calculated diffusion constant D_s , which he found could be related to the square of the soil porosity⁷ S and to the free diffusion coefficient D_f for the gases used in the following manner:

$$D_s = S^2 D_f \quad 2$$

Several workers, including Smith and Brown, have doubted the correctness of evaluating the rôle of the soil by means of the square of the porosity. However, it seems safe to state in general terms that the calculated diffusion constant D_s is related as follows:

$$D_s = f(\text{soil}) D_f = CD_f \quad 3$$

where $f(\text{soil})$ merely indicates some function of the soil that may be written as a constant C for a given soil under a particular set of conditions. Then to make the law of diffusion, as given in equation 1, applicable to the flow of gases through soils, the diffusion coefficient D_f must be replaced by CD_f . The expression then becomes

$$\frac{N}{At} = CD_f \frac{(dP)}{(dL)} \quad 4$$

⁷ See page 108 for definition of porosity.

If the flow is expressed in mass units and the differential expression for rate of change of partial pressure with distance along the direction of flow is replaced by the average value of the gradient $\frac{(P_b - P_t)}{L}$, where sub-

scripts *b* and *t* are introduced for convenience in later comparisons with data obtained in the present work and refer to partial pressures of CS₂ at the bottom and top of soil column respectively, equation 4 becomes

$$\frac{Q_m}{At} = CD_f \frac{(P_b - P_t)}{L} \quad 5$$

Here Q_m is the mass of gas in grams flowing through soil column, A is the cross-sectional area of soil column in square centimeters, and t is the time in seconds during which the quantity Q_m was collected. Though neither Buckingham nor Smith and Brown have carried the analysis to the point of writing the formal expression of a diffusional equation 5, such an equation must follow from their statements.

To test the validity of applying the law of diffusion, as written in 5, to the flow of gases under a partial-pressure gradient through soils, two sets of experiments were performed. A discussion follows.

Partial-Pressure Difference and Temperature Constant; Length of Soil Column Varied.—Using a given soil, successive samples of which were packed into tubes under as nearly uniform conditions as possible, the partial-pressure difference ($P_b - P_t$) and the temperature T were held constant while the effect of varying the tube length L was studied. Such tests were carried out on soils of five different textures. Table 2 contains the data for flow of CS₂ vapor measured as Q_m/At for different lengths of soil column.

The data suggest that the product Q_m/At by L is equal to a constant for each soil in a given condition as regards moisture content, compaction, and the like. The weighted mean⁸ value M of this product for each soil appears in the table. To provide a measure of the exactness with which the product $(Q_m/At) \times (L)$ is a constant for each soil, an estimate of the probable error of a single observation has been calculated by the method of Deming and Birge (1934), which permits an "optimum" estimate of the probable error to be made by combining observations on the five different soils. Since the method of Deming and Birge assumes that observations made on each of the five soils have the same precision, a condition not strictly true in the present case, the calculated "optimum" probable error is an approximation with a value of ± 0.695 . On the average, accordingly, there is an even chance that the product $(Q_m/At) \times (L)$ will fall within ± 0.695 of the true mean for each soil.

⁸ Weighted as to number of observations.

It is a necessary, but not a sufficient, condition that the product $(Q_m/At) \times (L)$ be a constant if the law of diffusion as given in equation 5 is to be followed. We cannot infer from this experiment that the law is obeyed. A second set of experiments is required to interpret more correctly the application of this diffusion law.

TABLE 2
CS₂ VAPOR FLOW AS A FUNCTION OF LENGTH OF SOIL COLUMN WITH
PARTIAL-PRESSURE DIFFERENCE AND THE TEMPERATURE CONSTANT

Soil texture	Number of observations	Length (L) cm	$Q_m/At \times 10^6$ gm/cm ² /sec.	$(Q_m/At)L \times 10^6$ gm/cm/sec.	Weighted mean $(Q_m/At)L \times 10^6$ gm/cm/sec.
Fine sand.....	3	10.65	1.97	21.0	19.6
	10	15.15	1.25	18.9	
	3	15.95	1.25	19.9	
	2	21.20	0.95	20.1	
	1	40.85	0.51	20.8	
Fine sandy loam....	1	10.20	2.44	24.9	24.8
	1	15.95	1.55	24.7	
	1	21.20	1.19	25.2	
	1	30.20	0.81	24.4	
Loam.....	2	10.65	2.14	22.8	21.1
	1	15.95	1.29	20.6	
	1	21.20	0.93	19.8	
	1	30.20	0.65	19.7	
Clay loam.....	1	10.65	2.06	22.0	24.3
	1	15.05	1.70	25.6	
	1	21.20	1.19	25.2	
	1	30.20	0.81	24.4	
Clay.....	1	10.05	1.88	18.9	20.1
	1	10.65	1.88	19.8	
	1	15.05	1.34	20.1	
	1	15.95	1.30	21.6	
	2	21.20	0.98	20.8	
	1	30.20	0.63	19.0	
	1	41.50	0.47	19.6	

Length of Soil Column Constant; Partial-Pressure Difference Varied by Altering Temperature.—The tube length L was now held constant, and the partial-pressure difference $(P_b - P_t)$ varied by changing the temperature of the apparatus. P_b , the partial pressure of the CS₂ in the volatilizing dish, directly depends on temperature. In table 3 the measured flows of CS₂, Q_m/At , are given in column 2; the corresponding gradients, $\frac{(P_b - P_t)}{L}$, in column 6.

This series of experiments permits more critical examination of the question whether the diffusion law of equation 5 is obeyed for the move-

TABLE 3
CS₂ VAPOR FLOW AS A FUNCTION OF PARTIAL-PRESSURE DIFFERENCE AND TEMPERATURE; LENGTH OF SOIL COLUMN CONSTANT
AT 14.00 CENTIMETERS

Temperature	Q	Q _m /At × 10 ⁶	Partial-pressure difference					$\frac{P_b - P_t}{L}$	$\eta \times 10^6$	$\frac{1}{\eta} \frac{P_b - P_t}{L} \times 10^{-6}$
			P _b		P _t					
			1	2	3	4	5	6	7	8

Run no. AFZ: Yolo fine sandy loam; moisture content, 2.85 per cent; apparent density, 1.332 gm/cc; porosity,* 45.9 per cent										
deg. C	mg/min.	gm./cm ² /sec.	mm Hg	mm Hg	mm Hg	mm Hg/cm	poise	mm Hg/poise/cm		
44.9	15.63	3.422	725.0	66.2	658.8	47.06	108.1	0.4353		
40.0	15.16	3.319	616.7	63.2	553.5	39.54	106.2	0.3723		
36.4	12.08	2.645	545.5	49.8	495.7	35.41	104.9	0.3376		
29.9	10.43	2.283	432.0	42.1	389.9	27.85	102.4	0.2720		
20.0	7.35†	1.609	297.5	28.7	268.8	19.20	98.6	0.1947		
20.0	7.32†	1.603	297.5	28.6	268.9	19.21	98.6	0.1948		
13.0	5.46	1.195	225.0	20.8	204.2	14.59	95.9	0.1521		
10.0	4.81	1.063	198.1	18.1	180.0	12.86	94.8	0.1357		

Run no. AGA: Yolo clay; moisture content, 5.73 per cent; apparent density, 1.216 gm/cc; porosity,* 47.3 per cent										
deg. C	mg/min.	gm./cm ² /sec.	mm Hg	mm Hg	mm Hg	mm Hg/cm	poise	mm Hg/poise/cm		
44.9	13.08	2.864	725.0	55.4	669.6	47.83	108.1	0.4425		
40.0	11.77	2.577	616.7	49.1	567.6	40.54	106.2	0.3817		
36.4	10.08	2.207	545.5	41.6	503.9	35.99	104.9	0.3431		
29.9	8.37	1.832	432.0	33.8	398.2	28.44	102.4	0.2777		
20.0	6.03†	1.320	297.5	23.5	274.0	19.57	98.6	0.1985		
20.0	5.93†	1.298	297.5	23.1	274.4	19.60	98.6	0.1988		
13.0	4.53	0.992	225.0	17.3	207.7	14.84	95.9	0.1547		
10.0	3.84	0.841	198.1	14.5	183.6	13.11	94.8	0.1383		

* For definition of porosity, see page 108.

† The CS₂ vapor flow first measured at this temperature. Then, without disturbing the soil columns, the flows were obtained for the other temperatures. The temperature was then restored to 20°C, and the final flows measured (marked †).

ment of CS_2 vapor through soil in response to a partial-pressure gradient. Under the experimental conditions, as the gradient $\frac{(P_b - P_t)}{L}$ increases, the temperature T must also increase. The possible effect of temperature on the CD_f term of equation 5 must be considered. C is presumably a constant dependent only on the soil and independent of temperature. According to kinetic theory, however, the free diffusion coefficient D_f depends on temperature. Its relation to temperature, according to Kennard (1938), may be approximated by

$$D_f \propto T^{1.75 \text{ to } 2} \quad 6$$

where for CS_2 the exponent is set equal to 2. (As given in *International Critical Tables*, vol. 5, p. 62. National Research Council. 1929.)

Now if the diffusion law postulated in equation 5 is to be followed, assuming C to be independent of temperature, then the mass flow of CS_2 per unit area per unit time, Q_m/At , plotted against the partial-pressure gradient $\frac{(P_b - P_t)}{L}$ should give a curve having at all points a slope equal to CD_f . Since T increases with $\frac{(P_b - P_t)}{L}$ and D_f increases as T^2 , the slope CD_f must increase with increasing values of $\frac{(P_b - P_t)}{L}$. Hence Q_m/At plotted as ordinates against $\frac{(P_b - P_t)}{L}$ as abscissas should not yield a straight line, but rather an upward-bending curve of increasing slope (figs. 5 and 6).

In these graphs the experimentally observed flow curve is compared with one drawn through a series of points calculated by assuming the diffusion law as given in equation 5. These values of flow, designated by $(Q_m/At)_d$, have been calculated in the following way:

Since duplicate determinations were available at 20°C , the experimentally obtained values of Q_m/At and $\frac{(P_b - P_t)}{L}$ at this temperature, together with the known value of the diffusion coefficient D_f at 20°C , have been used to give a mean value of the constant C of equation 5 for each soil. This has been assumed to be a reliable estimate of C . Now if C is a constant independent of temperature, it may be used with values of D_f to calculate $(Q_m/At)_d$ for each experimental value of $\frac{(P_b - P_t)}{L}$. (The sub-

script d is introduced to denote calculated values according to diffusion law.) Table 4 summarizes these calculations.

TABLE 4
CALCULATION OF CS₂ VAPOR FLOW AT VARIOUS TEMPERATURES USING THE DIFFUSION LAW

Temperature, deg. C	$D_f \times 10^8$ *	Run no. AFZ, Yolo fine sandy loam				Run no. AGA, Yolo clay			
		$\frac{P_0 - P_i}{L}$ mm Hg/cm	Mean of Ct	Calculated (Q_m/At) $\times 10^8$	Observed $Q_m/At \times 10^8$	$\frac{P_0 - P_i}{L}$ mm Hg/cm	Mean of Ct	Calculated (Q_m/At) $\times 10^8$	Observed $Q_m/At \times 10^8$
	$\frac{gm/cm^2/sec}{mm Hg}$			$gm/cm^2/sec$	$gm/cm^2/sec$			$gm/cm^2/sec$	$gm/cm^2/sec$
44.9	0.5352	47.06	0.1839	4.632	3.422	47.53	0.1470	3.763	2.864
40.0	0.5188	39.54	0.1839	3.773	3.319	40.54	0.1470	3.091	2.577
36.4	0.5070	35.41	0.1839	3.302	2.645	35.99	0.1470	2.692	2.207
29.9	0.4859	27.85	0.1839	2.489	2.283	28.44	0.1470	2.031	1.832
20.0	0.4547	19.20	0.1839	1.606	1.609	19.57	0.1470	1.308	1.320
20.0	0.4547	19.21	0.1839	1.606	1.603	19.60	0.1470	1.310	1.298
13.0	0.4332	14.59	0.1839	1.162	1.195	14.84	0.1470	0.945	0.992
10.0	0.4241	12.86	0.1839	1.003	1.053	13.11	0.1470	0.817	0.841

* Calculated from values of D_f for CS₂ appearing in Landolt-Bornstein (1923), 1.251, and given in $gm/cm^2/sec$. per millimeter of mercury difference in partial pressure per centimeter length.

† Mean calculated value of the constant of equation 5.

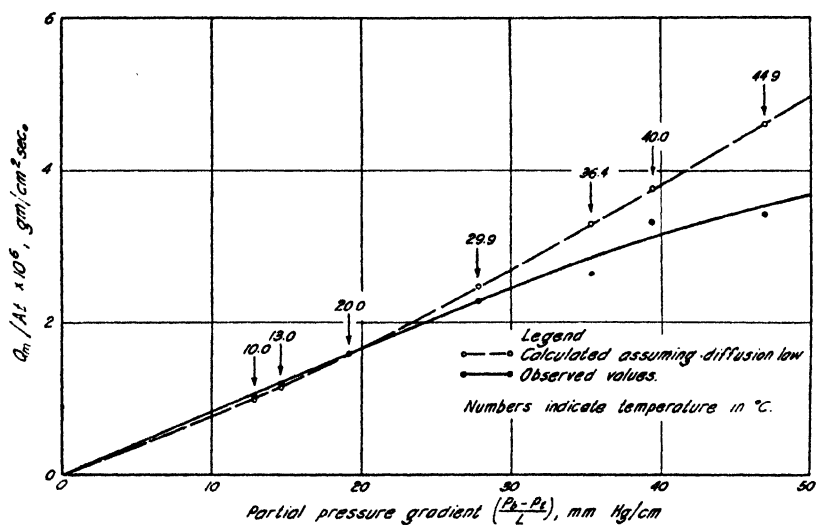


Fig. 5.—Departure of observed flow of CS₂ vapor from flow values calculated by assuming diffusion law for run no. AFZ (Yolo fine sandy loam).—

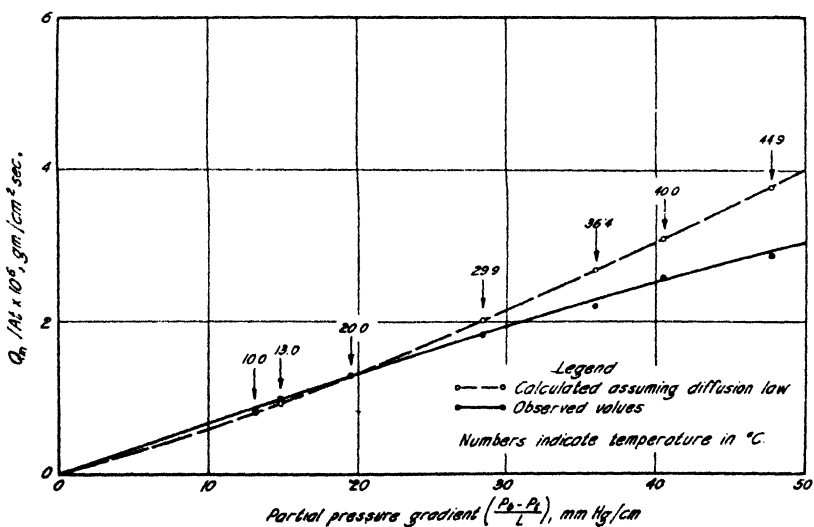


Fig. 6.—Departure of observed flow of CS₂ vapor from flow values calculated by assuming diffusion law for run no. AGA (Yolo clay).

Thus we observe experimentally that the law of diffusion is apparently not obeyed for the movement of CS_2 vapor through columns of laboratory-packed soils under a partial-pressure gradient. Buckingham and Smith and Brown were not in a position to discover a failure of the diffusion law because they worked at a fixed temperature.

Turning to the conditions for which the theory of diffusion was derived, we perceive a reason for the failure of the diffusion law to predict the observed flows of gas through the soil. In deriving the diffusion law, equation 1, which leads to equation 5, one considers only impacts between molecules. One ignores the possible effect of impacts between molecules and the confining walls. For discussion of the derivation of the law of diffusion, the reader is referred to any complete text on kinetic theory (for example, Loeb, 1934, or Kennard, 1938). In the usual experiments involving diffusion, impacts on the walls may be neglected, for the dimensions of the passageway through which the diffusional flow is occurring are large as compared with the mean free path of the gaseous molecules. In soils, however, it is extremely doubtful that the impacts with the walls of the pores can be neglected.

The law of diffusion is the only physical law of flow developed for flow at constant pressure under a partial-pressure gradient. Yet from considering the conditions imposed in its derivation, one could not expect this law to be followed for gaseous movement in soils under a partial-pressure gradient. Further, on the assumption of the previously stated relations between temperature and partial-pressure gradient, the failure of the law has been demonstrated experimentally. Inasmuch as the possible use of one of the laws of flow developed for total-pressure gradients, such as Poiseuille's, Darcy's (1856), or Knudsen's (1909) laws, for expression of flow under a partial-pressure gradient, involves considerations outside the scope of this present paper, the observed data have been fitted by an empirical equation.

Development of the Empirical Equation.—Assuming that flow is proportional to the partial-pressure gradient, one may write

$$\frac{Q_m}{At} = K \frac{(P_b - P_i)}{L} \quad 7$$

in which K is an empirical constant. This is an assumption commonly made in flow studies. Its validity for the present case must now be examined.

In the first series of experiments (cf. table 2), the relation of flow to the gradient was investigated by varying the length of the soil column L while holding the partial-pressure difference $(P_b - P_i)$ and the temperature T constant. Under these conditions, if flow is proportional to the gradient,

then the product (Q_m/At) (L) for any given soil condition must equal a constant, that is, $K(P_b - P_t)$. The data of table 2 show this to be the case.

Further, if the assumption is correct, $\frac{(Q_m/At)}{(P_b - P_t)}$ should, when L is fixed, equal a constant; or Q_m/At when plotted against $(P_b - P_t)$ or $\frac{(P_b - P_t)}{L}$ should give a straight line, that is, a curve of slope K .

Referring to figures 5 and 6, where Q_m/At as ordinates have been plotted against $\frac{(P_b - P_t)}{L}$ as abscissas, we see that a linear relation does not hold,

but rather the observed points fall along a downward-bending curve. Evidently some factor is operating to decrease the observed flow below that to be expected from a direct proportionality between the flow Q_m/At and the gradient $\frac{(P_b - P_t)}{L}$. Remembering that under the experi-

mental conditions the temperature increases with increasing values of $\frac{(P_b - P_t)}{L}$, it appears that the constant of equation 7 must contain a factor which causes its magnitude to diminish with increasing $\frac{(P_b - P_t)}{L}$ and temperature T . Equation 7 must be extended.

The viscosity of the CS_2 vapor, which increases with temperature, has not been taken into account. If increased viscosity causes the decrease in the magnitude of the constant of equation 7, then the viscosity η must be introduced to modify equation 7 as follows:

$$\frac{Q_m}{At} = K \frac{1}{\eta} \frac{(P_b - P_t)}{L} \quad 8$$

This parallels the introduction by Emanuelli (1927) and by Wyckoff and co-workers (1933) of a viscosity factor into the equation expressing Darcy's law to give in that equation a constant characteristic only of the porous medium and independent of the temperature and the fluid used.

Now, if the empirically developed equation 8 is to be obeyed by gases moving through soil under a partial-pressure gradient, and if the constant K of the equation is to be truly constant for a given soil, then values of Q_m/At as ordinates plotted against $\frac{1}{\eta} \frac{(P_b - P_t)}{L}$ as abscissas

should yield a straight line of constant slope equal to K and passing through the origin. Such a plot has been made in figure 7, and the experimental points fitted to a linear function by the method of least squares.

The relation between the viscosity of gases and temperature may be expressed according to Sutherland (1893) as follows:

$$\eta = \eta_0 \sqrt{\frac{T}{T_0}} \left(\frac{1 + \frac{C_s}{T_0}}{1 + \frac{C_s}{T}} \right) \quad 9$$

where η and η_0 refer to the viscosities at the absolute temperatures T and T_0 and where C_s is a constant characteristic of the particular gas. A value of $C_s = 496$ calculated by Titani (1933) according to a formula proposed by Arnold (1933) has been used in equation 9 to obtain the values of η appearing in column 9 of table 3. This value of C_s agrees closely with Titani's experimental values and with those calculated by Rankine's (1910) formula. The value $\eta = 96.4 \times 10^{-6}$ poise at 14.2°C , taken from Suhrmann (1923), has been used as a base value in Sutherland's formula for converting to the temperatures of the experiments.

The empirically developed equation 8 will be recognized as a special form of the more general algebraic equation of the first degree, $y = a + \beta x$; or, using the previous symbols,

$$\frac{Q_m}{At} = a + \frac{K'}{\eta} \frac{(P_b - P_i)}{L} \quad 10$$

in which the intercept a has been taken equal to zero. The intercept a has been taken as zero in writing equation 8, for we have assumed that when $\frac{(P_b - P_i)}{L} = 0$, Q_m/At would be zero; that is, when the gradient was zero,

there would be no net flow of CS_2 . One would expect this to be the case, but in order to justify setting $a = 0$, one must fit the data by least squares to the general form of the first-degree equation—that is, equation 10—and obtain the least squares values of the constants a and K' . To determine whether the calculated values of the intercept a depart significantly from zero, one may proceed as follows:⁹

Using the least squares values of the constants a and K' , calculate a value of Q_m/At for each observed value of $\frac{(P_b - P_i)}{L}$. From the residuals, $Q_m/At - (Q_m/At)_c$ (where the subscript c refers to the calculated value), calculate the estimated probable error of a single observation r_s' by

$$r_s' = 0.6745 \sqrt{\frac{\sum v^2}{(n - 2)}} \quad 11$$

⁹ This procedure has been developed in collaboration with Mr. P. R. Day.

where v is the residual $Q_m/At - (Q_m/At)_e$ and n the number of observed points. The primes on r_a' and K' are introduced to distinguish these values from corresponding unprimed values calculated when a was taken as zero. Now, from this value of the probable error of the intercept a , given by the symbol r_a' , using the following relation as given by Birge (1932),

$$r_a' = r_s' \left(\frac{\Sigma x^2}{n \Sigma x^2 - (\Sigma x)^2} \right)^{1/2} \quad 12$$

where quantities within the parentheses refer to the least-squares working table, in which x represents the observed values of $\frac{1}{\eta} \frac{(P_b - P_t)}{L}$ for the n observations.

One must bear in mind that the results of statistical analysis apply in a negative manner. As we have seen, there is some reason to believe that the intercept a should be zero. The question now is, do the calculated values of a and the estimated probable error of the intercept, r_a' , support this contention? The "u-test" (normal probability integral) of Deming and Birge (1934) may be applied to express the chance that a given calculated value of a departs significantly from zero. If the chances that the calculated value of a does depart significantly from zero are found to be high, then the theoretical contention $a = 0$ becomes doubtful. On the other hand, unless the chances are high for a significant departure, one can say the theoretical contention $a = 0$ is not contrary to experiment.

Applying this analysis to the data of table 3 and figure 7, the values given in the following tabulation are found for the intercept a ; the constant K' ; the estimated probable errors of a single observation r_s' and of the intercept r_a' ; and the probability P that the calculated value of a departs significantly from zero:

	a	K'	r_s'	r_a'	P
Run no. AFZ	-0.0275×10^{-6}	8.28×10^{-12}	$\pm 0.0938 \times 10^{-6}$	$\pm 0.0905 \times 10^{-6}$	0.15
Run no. AGA	-0.0356×10^{-6}	6.66×10^{-12}	$\pm 0.0309 \times 10^{-6}$	$\pm 0.0298 \times 10^{-6}$	0.55

On theoretical grounds there is good reason to take $a = 0$; and the statistical analysis has shown that this is *not* contrary to the experimental facts. In the more doubtful case, AGA, the probability is very close to that to be expected from pure chance. We can therefore set $a = 0$ and accept the form of the empirical equation of flow 8.

Now, using the form of equation 8, that is, setting $a = 0$, the best least-squares values of K were obtained, together with their estimated probable errors r_K calculated according to Birge (1932), using

$$r_K = r_s' \left(\frac{n}{n(\Sigma x^2) - (\Sigma x)^2} \right)^{1/2} \quad 13$$

Here r_s is the estimated probable error of a single observation having set $\alpha = 0$, and the quantities within the parentheses have the same significance as in equation 12. The following tabulation gives the values of K , which we shall hereafter call the permeability¹⁰ and express as gram-

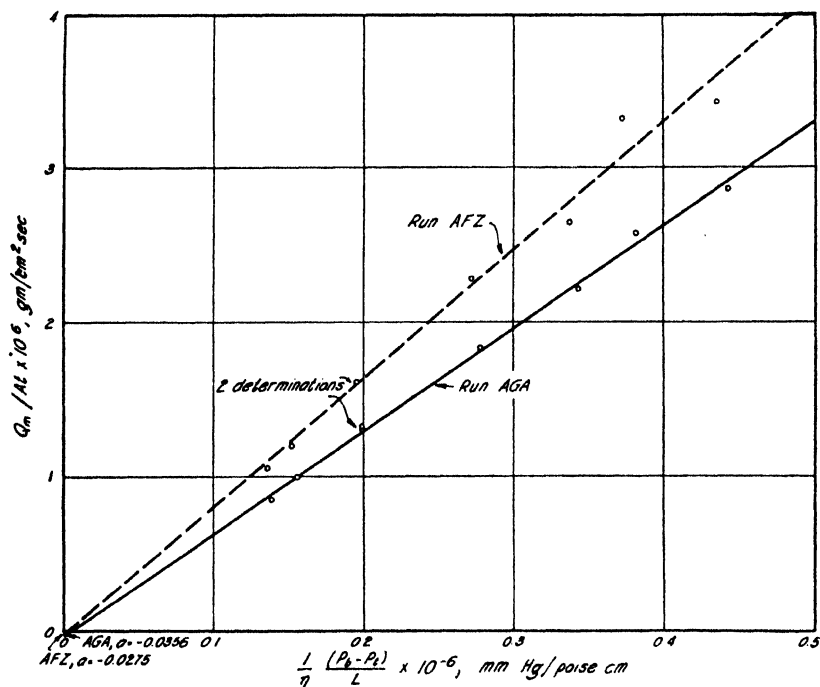


Fig. 7.—Observed flow of CS_2 vapor plotted (by least-squares line) according to the empirical equation: $\frac{Q_m}{Al} = \frac{K}{\eta} \left(\frac{P_b - P}{L} \right)$.

poises/sec./ cm^2 per unit partial-pressure gradient—that is, per millimeter of mercury difference in partial pressure/cm.

	Soil	K
Run no. AFZ.....	fine sandy loam	$(8.192 \pm 0.322) \times 10^{-12}$
Run no. AGA.....	clay	$(6.542 \pm 0.109) \times 10^{-12}$

Relation of the Empirical Equation to Other Physical Laws.—Mention should be made of the relation of the measured flow of CS_2 vapor through

¹⁰ Some workers have assigned the word permeability specifically to the constant of Darcy's law. In a more general sense, permeability is an expression of the ability of fluids to pass through a porous material. The constant of Darcy's law calculated for a particular porous material is one means of evaluating this ability. In this paper the writer evaluates this property by using the constant K of equation 8. For brevity this constant K will be referred to as the soil permeability.

the soil, and the empirical expression developed for it, to the laws of flow derived from kinetic-theory considerations for flow under total-pressure gradients. Poiseuille's law takes into account impacts between molecules and impacts between molecules and the wall. It is derived by equating the momentum caused by the pressure drop in flowing through a tube to the momentum lost by viscous drag on the walls. If one assumes that such laws can be applied to flow under partial-pressure gradients, one might expect the CS_2 flow observed in these experiments to be governed by Poiseuille's law, or by Darcy's law with the added viscosity term that can be shown to reduce to the same form as Poiseuille's law. For the flow of gases, Poiseuille's or Darcy's law may be written:

$$\frac{Q_m}{At} = \frac{K''}{\eta} \frac{M}{R_0 T} \frac{(P_1^2 - P_2^2)}{L} \quad 14$$

in which K'' is a constant, M the molecular weight of the gas flowing, R_0 the universal gas constant, T the absolute temperature, and P_1 and P_2 the total pressures at the ends of the tube. The derivation of Poiseuille's law implies conditions such that viscous transfer of momentum from the moving molecules to the walls can occur. This requires that the mean free path of the molecules λ , which for CS_2 molecules at atmospheric pressure is of the order of magnitude of 0.5×10^{-5} cm., or 0.05 micron, be small as compared with the radius R of the tube through which the gas flows.

The requirement that λ be small as compared with R in order that Poiseuille's law be followed casts doubt upon the applicability of this law to soils where some of the pores, at least, may be of the order of 0.05 micron. Knudsen (1909) has derived a law for flow under conditions such that λ is of the same order as R . In his derivation (see Loeb, 1934), he considers impacts between molecules and wall to be more important than impacts between molecules, and arrives at the following law:

$$\frac{Q_m}{At} = \frac{K'''}{\sqrt{T}} \frac{(P_1 - P_2)}{L} \quad 15$$

Here K''' is another constant, and T is the absolute temperature. Since 0.05 micron would seem small for pores in a granular soil, one might expect the measured flow of CS_2 to fall between the flows as predicted by Poiseuille's and Knudsen's laws, provided we consider the interchangeability of the partial-pressure difference ($P_b - P_i$) and the total pressure difference ($P_1 - P_2$).

It is interesting now to compare the empirically established flow equation 8,

$$\frac{Q_m}{At} = \frac{K}{\eta} \frac{(P_b - P_i)}{L}$$

with equation 15 expressing Knudsen's law. Evidently the empirical equation is closely related to Knudsen's law, since η varies approximately as $\sqrt{T}$. (See equation 9.)

For purposes of this project, however, we shall use the empirical expression 8, which is convenient and which well fits the experimental data. The ability of a soil to transmit CS_2 under given conditions will be specified by the evaluation of the constant K in the empirical flow equation, which we have referred to as the soil permeability. Wyckoff and co-workers (1939) have proposed a standard unit for permeability, the "darcy." Since this unit, as defined, involves flow expressed on a volume basis, it will not be used. Soil permeabilities will be expressed as gram-poisees per second per square centimeter per millimeter mercury difference in partial pressure of CS_2 per centimeter length.

DISCUSSION

Under the laboratory conditions of this experiment, the soil porosity, when expressed according to Buckingham (1904), appears to be the controlling factor on the permeability of the soil to CS_2 vapor. The degree of compaction (the apparent density value) and the soil moisture content apparently influence permeability to an extent dependent on their effect on porosity.

Buckingham defines porosity as the volume of gas in a given over-all volume of soil divided by that total volume; that is, it is an expression for the percentage of gas by volume:

$$S = \left(\frac{V_g}{V_g + V_w + V_s} \right) 100$$

Here V_g , V_w , and V_s represent the volumes of the gas, water, and solid phases respectively. This definition of porosity should not be confused with the frequently used concept wherein porosity is given as the ratio of the nonsolids volume to the total volume. This latter porosity expresses the volume occupied by the gas and water phases, whereas Buckingham's expression considers the volume occupied by the gaseous phase *only*. Throughout this discussion porosity is used as defined by Buckingham. This manner of expressing porosity has also been followed by Green and Ampt (1911, 1912) and by Smith and Brown (1933).

Figure 8 presents graphically the experimental relation between the soil permeability for CS_2 vapor and the soil porosity for Yolo fine sand. Whereas the points at the high-porosity end were obtained by compacting air-dry soil, the points at the low-porosity end were derived from studies on soils at different moisture contents. On extrapolation, note that the permeability approaches zero, not at zero porosity, but at a

porosity near 26 per cent. According to experiments with other textures—fine sand, sandy loam, loam, and clay—permeability is also governed by porosity, but the relationship is not linear (fig. 9). Again, it should be noted that the permeability on extrapolation approaches zero at 26–29 per cent

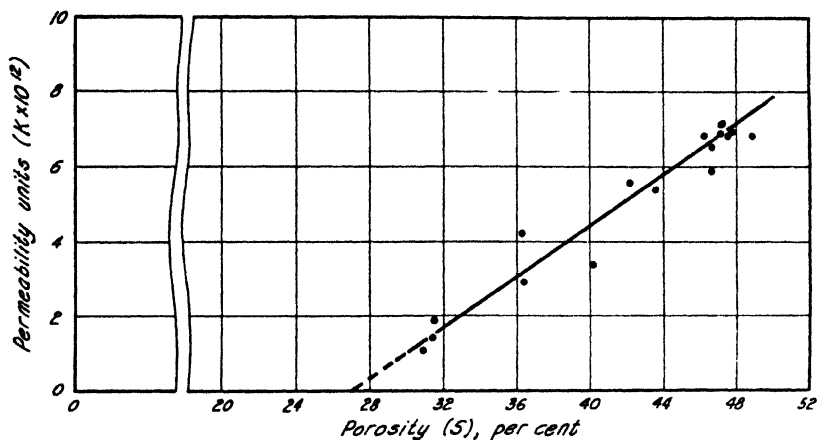


Fig. 8.—Relation of soil porosity to the permeability of the soil for CS_2 vapor in Yolo fine sand.

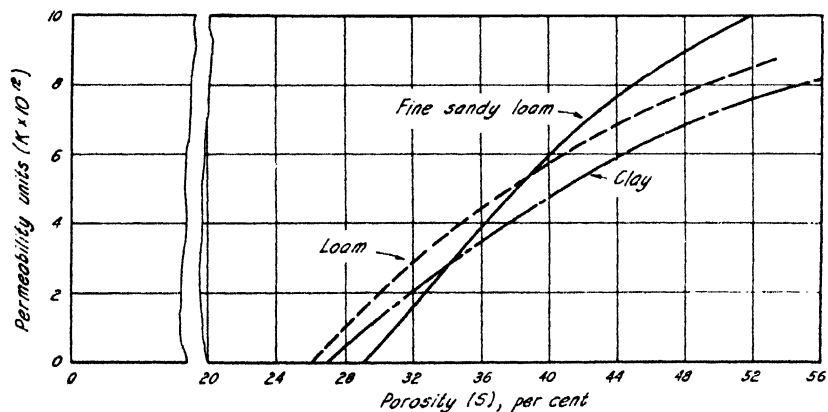


Fig. 9.—Relation of soil porosity to the permeability of the soil for CS_2 vapor in Yolo fine sandy loam, Yolo loam, and Yolo clay.

porosity. This finding agrees with Green and Ampt, whose data for soils and for systems of glass beads, when extrapolated, indicate that the permeability would approach zero as the porosity decreased to the value near 30 per cent. Smith and Brown, experimenting with air-dry soils having a porosity range of 35 to 65 per cent, concluded that the flow of CO_2 was a linear function of porosity. The rather bad scatter of their data

over this range of porosity does not, however, allow an extrapolation to determine whether flow would approach zero at a finite porosity.

The literature contains several references to studies on the relation between porosity and permeability. The results reported are not in agreement, for Fancher, Lewis, and Barnes (1933) state there is no consistent relation between porosity and permeability; Muskat and his colleagues (Muskat and Botset, 1931, Wykoff, *et al.*, 1933) declare that porosity cannot alone indicate the permeability accurately, but that porosity may be the primary property in determining permeability, and Buckingham, Green and Ampt, Howe and Hudson (1927), and Smith and Brown agree that permeability varies in the same direction as porosity, but disagree as to the extent to which the two are related.

Different soils vary in the ratio of continuous to discontinuous air spaces. This would seem to be a contributory factor in causing the soil textures to show unequal permeabilities to CS_2 at a given total porosity. *Texture* is a term indicating the size distribution of particles in a soil. Differences in the properties of soils of unlike texture are caused not only by texture, but also by another factor—namely, structure. Structure expresses the arrangement of the individual grains and aggregates that make up the soil mass. It must, then, affect the shape and distribution of the voids in the soil, and hence the proportions of continuous to non-continuous pores. Although laboratory samples of soils of various textures still possess structural differences, these differences have been reduced. The comparatively small differences in permeability shown by the unlike-textured soils in figure 8 would be expected to be greater under the natural structure conditions in the field.

Compaction.—Soils are frequently characterized by a statement of the degree of compaction, which is often expressed in terms of the “apparent density” ρ_a of the soil calculated from the following relation:

$$\rho_a = \frac{\text{mass of oven-dry soil}}{\text{apparent or total volume of this soil}}$$

In a gross way the compaction of a soil expresses the closeness with which the soil particles have been squeezed together. The more compact a given soil, the smaller the pores or passageways between the individual particles. Since the degree of compaction is one factor controlling the free porosity of the soil, we should, from the previous discussion, expect the soil permeability to be a function of the apparent density value. Figures 10 and 11 give typical illustrations of this relation, using Yolo fine sandy loam and Yolo loam in the air-dry state.

Compaction studies were first to be undertaken. The rather bad scatter

of values could probably be reduced if the work were to be repeated now that the apparatus and technique have been perfected.

Judging from these studies on laboratory-packed granular soils, the

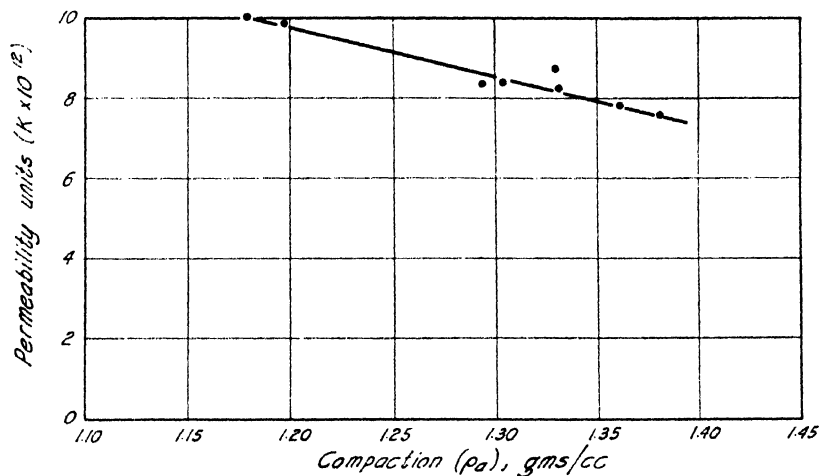


Fig. 10.—Influence of soil compaction (apparent density) on the permeability of the soil for CS_2 vapor in Yolo fine sandy loam, at a soil moisture content of 3.00 per cent.

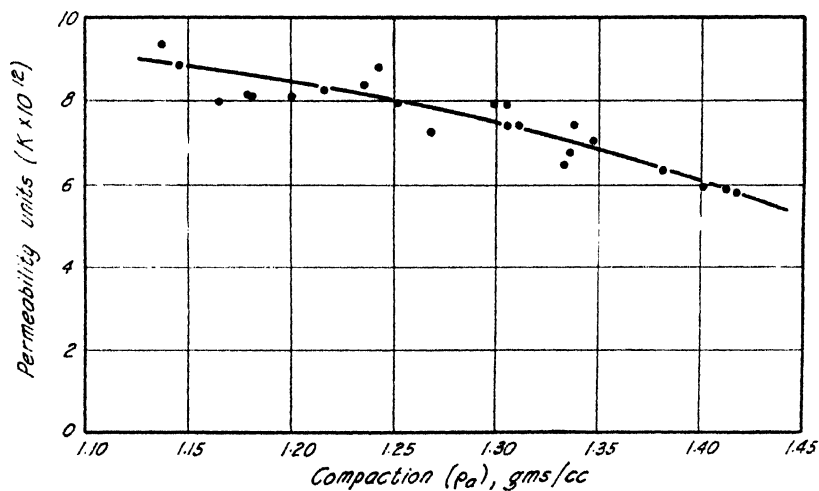


Fig. 11.—Influence of soil compaction (apparent density) on the permeability of the soil for CS_2 vapor in Yolo loam, at a soil moisture content of 3.70 per cent.

influence of compaction on the permeability depends on the change in porosity produced. This statement agrees with the views of Smith and Brown. It is to be expected that the relation between compaction and

permeability will be modified by structure. These studies have all been made on soils possessing necessarily artificial structures.

Field measurements show compaction to vary between rather wide limits, even for a given texture. For the Yolo Series of soils, field determinations on different textures gave a mean density value of 1.32.¹¹ Though the range of compactions obtainable in these laboratory studies did not include all values experienced in the field, such curves as figures

TABLE 5
EFFECT OF MOISTURE ON THE PERMEABILITY OF SOILS TO CS₂ VAPOR*

Soil type and run no.	Moisture equivalent	Field capacity	Soil moisture content at time of run	Permeability (calculated to a constant ρ_a)
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	$K \times 10^{12}$
Fine sand:				
ADH-W.....	6.82	11.6	2.56	6.67
AFP.....	6.82	11.6	12.0	2.33
AFR.....	6.82	11.6	17.0	0.42
Fine sandy loam:				
AFZ.....	17.26	18.0	2.85	9.61
AEY.....	17.26	18.0	18.1	0.50
AEW.....	17.26	18.0	18.8	0.12
Loam:				
ACW-DR.....	22.99	22.4	3.82	8.86
AFG.....	22.99	22.4	22.4	0.82
AFF.....	22.99	22.4	23.5	0.60
Clay:				
ACD-L.....	30.44	31.3	6.10	8.10
AFH, AFS.....	30.44	31.3	31.4	0.26
AFI.....	30.44	31.3	32.3	0.06

* Degree of compaction constant for each texture.

9 and 10 do indicate the order of magnitude of differences in permeability that might be expected within the range commonly found in the field soils.

Field plots established on the University Farm at Davis to study the movement of CS₂ vapor through the soil indicated that plowsoles could seriously hamper the distribution of the vapor in the soil.¹² Unfortunately we do not have any measurements of the apparent densities on these particular plowsoles or on the undisturbed portion of the profiles of these soils, but Shaw and Bodman¹³ have made such determinations on a Ramona sandy loam. They found that the plowsole had apparent density values as high as 1.95, whereas the undisturbed soil had a value of 1.20.

¹¹ From the records of the Division of Irrigation Investigations and Practice.

¹² Unpublished data by A. S. Crafts and R. N. Raynor.

¹³ Shaw, C. F., and G. B. Bodman. The plowsole. Division of Soils leaflet. 1928. (Mimeo.)

The range of compaction covered in the curves of figures 10 and 11 must be greatly extended to include such a value as 1.95. To give an approximation to the effect of plowsoles on permeability to CS_2 vapor, the curve for fine sandy loam (fig. 10) has been extrapolated to an apparent density value of 1.95. This gives a permeability of 0.5 to 1.0 unit. (See page 108 for definition of unit.) By comparing this low value of permeability with those given in figure 10, one may see more adequately the possible effect of compaction on permeability.

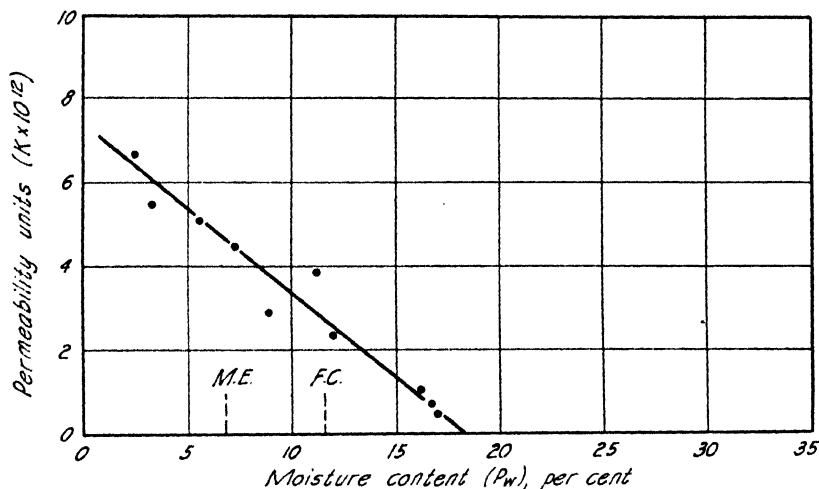


Fig. 12.—Influence of soil moisture content on the permeability of the soil for CS_2 vapor in Yolo fine sand, calculated to an apparent density of 1.325 grams per cubic centimeter.

Moisture Content.—The moisture content of the soil affects its permeability to CS_2 vapor more than does any other variable studied. The addition of water to soil can greatly reduce the free porosity. Table 5 gives the permeabilities of four soils for the air-dry state and for moisture contents near their field capacities. Figures 12 and 13 plot permeability against the soil moisture content for two soils—Yolo fine sand and Yolo fine sandy loam. Although points at the air-dry and field-capacity ends of the curves are relatively easy to obtain, the intermediate moisture contents present many difficulties. To wet a soil uniformly to a moisture content below the field capacity special techniques are required. Fairly satisfactory methods have been devised to obtain the desired moisture contents, but it has been necessary to store the moistened soils for many months to achieve uniform moisture distribution.

Since a certain variation in the apparent density value of successive

columns of packed soil is inevitable, a correction to constant apparent density for each texture has been made in the values of permeability K recorded in table 5. This is necessary in order to have the moisture content the only operative variable. The corrected K has been calculated from the observed K by assuming that the variation of K with change in apparent density is proportional to the change in free porosity produced by the change in apparent density.

Perhaps the most striking and significant observation made in these studies is the great reduction in permeability with increasing moisture content. With the sand, permeability approaches a very low value at

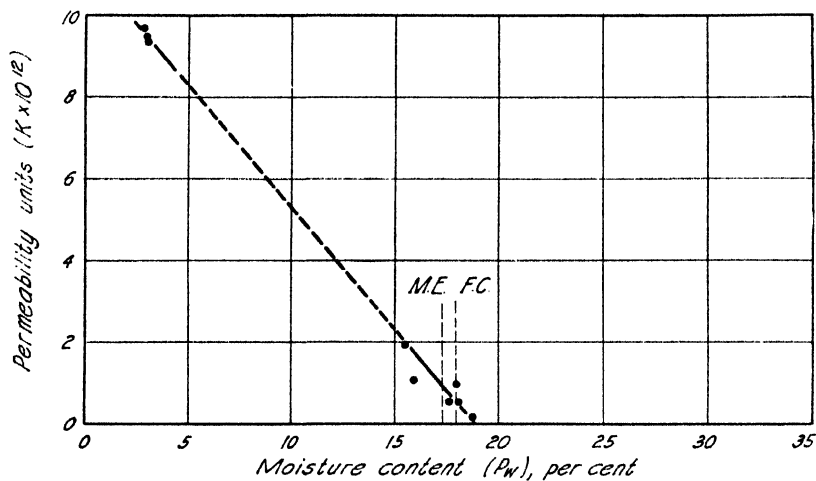


Fig. 13.—Influence of soil moisture content on the permeability of the soil for CS_2 vapor in Yolo fine sandy loam, calculated to an apparent density of 1.258 grams per cubic centimeter.

moisture contents near the field capacity, a fact possibly explainable on the basis of the large average grain size with correspondingly large channels between the particles. Further addition of moisture to the sand, however, does reduce the permeability to a low figure. This observation of very low permeability to CS_2 vapor in soils at their field capacity should be important in interpreting soil-fumigation studies carried out under field conditions and in soil-aeration relations in general.

SUMMARY

This investigation was undertaken to establish quantitatively the relation that each of several soil factors bears to the movement of CS_2 vapor through the soil. Success or failure in using CS_2 for weed and fungus control depends on the ability of the CS_2 to move in the soil and on the pre-

vention of its escape from the soil surface during and immediately after treatments. Satisfactory field application must be based on a knowledge of the effect that each soil factor, including soil porosity, texture, degree of compaction, and moisture content, has on CS_2 movement in and out of the soil.

The method of field application of CS_2 for controlling deep-rooted perennials is briefly reviewed.

The comparatively limited literature on gaseous movement in soils is discussed. In normal soil the gaseous phase throughout is at a *constant* pressure, the movement of CO_2 and O_2 , and other gases normally present, as well as the movements of fumigants that may be introduced, results from differences in concentration or *partial* pressures of the particular gas from point to point. This problem of flow of gases in soils at constant total pressure in response to a partial-pressure gradient is considered in relation to the more generally treated problem of gaseous flow in response to a total-pressure difference.

The soil whose gaseous permeability is to be measured is packed into tubes to a known compaction and a definite moisture content. A shallow dish is sealed to the lower end of the soil tube into which the liquid CS_2 is measured, and an "air-sweeper" is attached to the upper end of the soil tube. The CS_2 is vaporized in a shallow dish, and the vapors, moving upward through the soil and rising from its upper surface, are collected by the air-sweeper and carried into absorber columns, where the amount of CS_2 passing through the soil may be chemically determined. The apparatus required is fully described.

The method used possesses several advantages besides having the flow take place at a constant total pressure. It provides a system permitting a continuous record of the flow of CS_2 vapor. For general soil permeability and soil-texture studies, the use of a gas like CS_2 , which does not normally occur in soils and does not alter the soil structure, eliminates the complexities involved in using CO_2 , which is affected by biological activity.

Judging from the experimental values for the flow of CS_2 vapor through tubes of artificially packed soil carried out at different temperatures, the law of diffusion implied by Buckingham (1904) is not followed. A reason for the failure of the classical diffusion law to apply for gases moving in soils is suggested from an analysis of the kinetic-theory conditions imposed in the derivation of the law.

An empirical equation of flow has been developed to express the measured flows of CS_2 vapor. The relation of this empirically established equation to other physical laws of flow is discussed.

Under the conditions of the experiments, the free porosity is apparently the controlling factor on the permeability of the soil to CS_2 vapor. The

permeability of these artificially packed soil columns has been found to approach zero, not at zero free porosity, but in a porosity range of 26 to 29 per cent. These relations are graphically presented for several textures.

Permeability is found to vary with soil texture, but the differences are smaller than would be expected under natural structure conditions of the field. The degree of compaction of the soil is found to control permeability in the extent to which the free porosity is changed. As field-plot trials have shown, compact layers in soils, such as plowsoles, will interfere seriously with the distribution of CS_2 .

The moisture content of the soil affects the permeability of the soil to CS_2 vapor more than does any other variable studied. Great reductions in permeability have been found with increasing moisture content. Permeability approaches a very low value at moisture contents near the field capacity for all textures except fine sand.

ACKNOWLEDGMENTS

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HYDROLOGIC STUDIES OF THE PUTAH CREEK AREA IN THE SACRAMENTO VALLEY, CALIFORNIA^{1,2}

MARTIN R. HUBERTY³ AND C. N. JOHNSTON⁴

INTRODUCTION

THE DEEP ALLUVIAL FILL of Putah Creek forms a storage basin from which much irrigation water is pumped. Continued and expanding demand upon the underground water supply has caused a gradual recession in the water plane. This condition leads many farmers to question the permanency of their water supply.

The College of Agriculture at Davis is located within the basin of Putah Creek. In years of low rainfall, the underground basin is its sole source of water supply. Hence, since the early days of the institution, the Division of Irrigation has observed underground water conditions on the University Farm.

The deficient rainfall of the winter of 1930-31 emphasized the need for a comprehensive study of the water supply in the Putah Creek area. Although Bryan (2)⁶ studied the basin in 1912, conditions have changed materially since that date. An informal project, outlining a study to supplement existing information on the water supply and the pumping conditions of the area, was formulated by the divisions of Agricultural Engineering, Chemistry, and Irrigation. In the summer and fall of 1931 and the spring of 1932, information was secured on the characteristics of the underground basin, on the quality of water with special regard to

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⁵ Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

boron content, and on the pumping plants. The findings were presented in a typewritten report to the Director of the College of Agriculture at Davis in 1932.

Some phases of the 1931-32 investigation have been continued by the Division of Irrigation. This publication summarizes the combined results of about twenty-five years' observations.

PHYSIOGRAPHY OF THE AREA

Putah Creek rises on the eastern slope of the Coast Range south of the Cache Creek basin and north of the Napa Valley. Drainage water from Mt. St. Helena passes southeastward through Putah Creek Canyon to

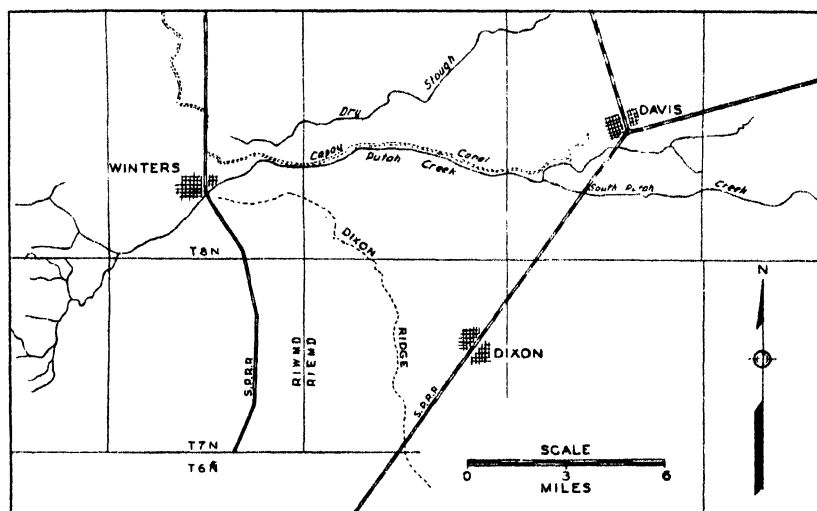


Fig. 1.—Lower basin of Putah Creek.

the Putah Creek lower basin. This discussion concerns the lower basin rather than the area from which the flow is derived. The upper basin is a rugged terrain ranging from an altitude of 5,000 feet at the head waters to about 125 feet at the upper end of the lower basin. The mean annual precipitation varies from a maximum of 100 inches, recorded at Helena Mine on the northern slope of Mt. St. Helena, to a normal of 28 inches in the lower foothills. The average annual precipitation along the central portion of the upper basin is about 40 inches. The chief tributaries of the upper basin of Putah Creek are Soda Creek from the north and Pope Creek from the west. Because the terrain is rugged, rain water moves rapidly to the stream beds, producing discharges of considerable volume through the lower basin.

Two suitable reservoir sites are available in the main bed of the upper basin—one about 6 miles west of Winters, the other near Guenoc. A reservoir at either site would be beneficial in equalizing runoff from the basin.

Figures 1 and 2 show the plan view of the upper and lower basins of the creek. The division between the two areas lies several miles west of the town of Winters, approximately as figures 1 and 2 are divided.

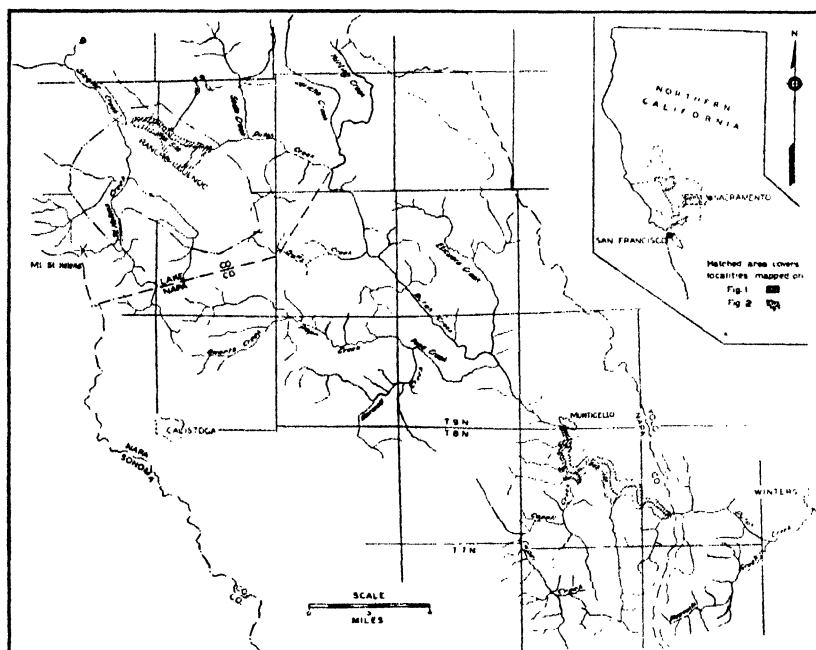


Fig. 2.—Upper basin of Putah Creek.

Figure 3 presents the geological aspects of the two areas. One may see that the area includes a variety of soils and rock formations. The lower basin is composed of products of decomposition of the upper. Since water has borne most of the disintegrated matter away from the upper basin, the stream bed there contains little loose material. Almost no seepage loss occurs, accordingly, in the stream flow while it traverses the upper basin.

The present bed of Putah Creek forms the boundary between Yolo and Solano counties as it crosses the major part of the valley floor eastward from the upper basin. The lower basin itself is a fanlike area spreading outward from near Winters to the northeast and southeast for about 20 miles. It retains the typical form of alluvial fan deposits, in which the

surface slopes away from the apex of the fill and also away from the immediate bank of the stream whose waters have formed it. Scars on the surface indicate the wanderings of Putah Creek over the area in comparatively recent times. One such surface trace, the Dixon ridge, may be followed from Winters directly to Dixon.

There is evidence that Putah Creek did not always find its outlet to the east from the mountains. Judging, however, from the hundreds of

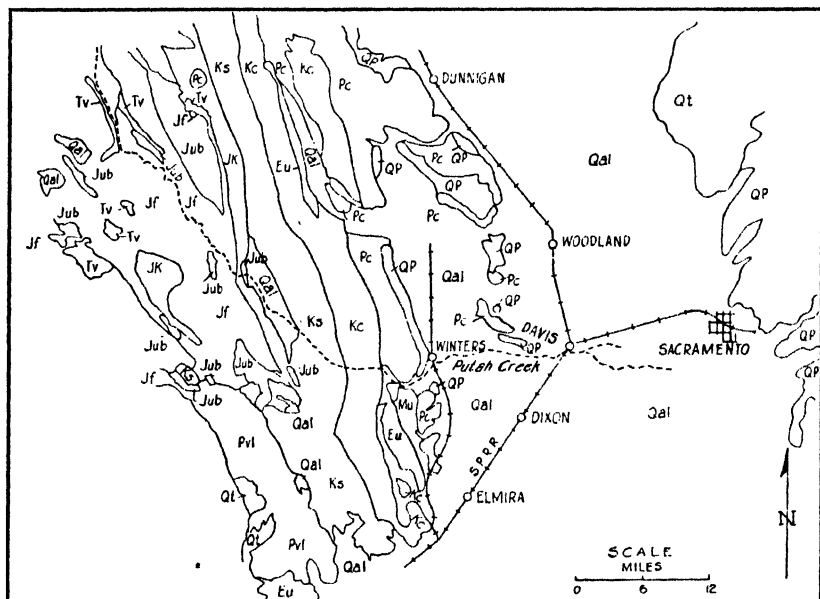


Fig. 3.—Geologic map of Putah Creek drainage basin and adjacent areas: *QP*, Quaternary and Upper Pliocene sediments; *Qal*, alluvium; *Pc*, undivided Pliocene nonmarine sediments; *Kc*, Upper Cretaceous marine sediments; *Mu*, Upper Miocene marine sediments; *Eu*, Upper Eocene marine sediments; *Pvl*, Lower Pliocene volcanics and interbedded sediments; *Qt*, terrace deposits; *Jub*, Jurassic ultra-basic intrusives; *JK*, Knoxville formation; *Jf*, Franciscan group; *Tv*, Undivided Tertiary volcanics; and *Ks*, Lower Cretaceous marine sediments. (Data from O. P. Jenkins, Chief Geologist, California State Division of Mines.)

feet depth of water-deposited materials throughout the lower basin, the present outlet has been used for a long time. The well-driller encounters several layers of gravel throughout the lower basin. Judging from their composition, all these are related to the formations still in place in the mountains to the west. The gravels and other strata slope with the dip to the east—as might be expected, since they were laid down by water moving from the west. The large particles represented by the water-bearing, coarser gravels were deposited during periods of heavy

stream flow with high water velocities, while materials grading down to clays were deposited in quieter water. The presence of considerable depths of both types of deposit and of intermediate classifications suggests a wide range in conditions of runoff and deposition.

Because Putah Creek has laid down all these upper strata, its bed cuts across many of the older porous layers, thereby permitting its waters to replenish the underground supply.

Around Davis and eastward, a blue-clay stratum underlies the soil surface at a depth of about 350 feet. This blue coloring is generally assumed by geologists to result from deposition in relatively deep water where oxidation processes were restricted. Such deposits are found where the sea has covered an area such as the Sacramento Valley.

RESULTS OF THE INVESTIGATION

Methods and Scope of Work.—In this study of the problems of water distribution and supply in the lower basin of Putah Creek, consideration was given to: (1) ground-water levels; (2) water-bearing strata; (3) properties of underground waters; (4) climatic conditions of and runoff from the Putah Creek basin; (5) zones of ground-water recharge; and (6) interpretation of data.

Water levels may be presented as measured depths to water from the ground surface or as elevations of such water surfaces. In this paper all elevations are referred to mean sea level datum which is zero elevation. Several types of sounding devices are available for measuring the depth to water, which is best obtained when the well is not being pumped.

Although most of the data on thickness and position of water-bearing strata were obtained from well-drillers' records, some were secured by College of Agriculture investigators who observed the drilling.

The properties of the waters noted were temperature and chemical composition. The water samples for chemical analysis were collected and water-temperature readings were made while the well was being pumped. Chemical analyses are presented in detail in the companion paper (1), but in the present paper boron concentrations are referred to as a possible means of determining sources of underground water supply.

Long-time records of weather and of storm runoff in the Putah Creek area are available. Such information is valuable for estimating the probable available water supply of the area and for explaining fluctuations in underground water levels.

Because graphic presentation provides the best method for showing comparisons in the periodicity of ground-water levels and for relating location with such factors as temperatures and chemical composition of waters, it has been preferred to the tabular method.

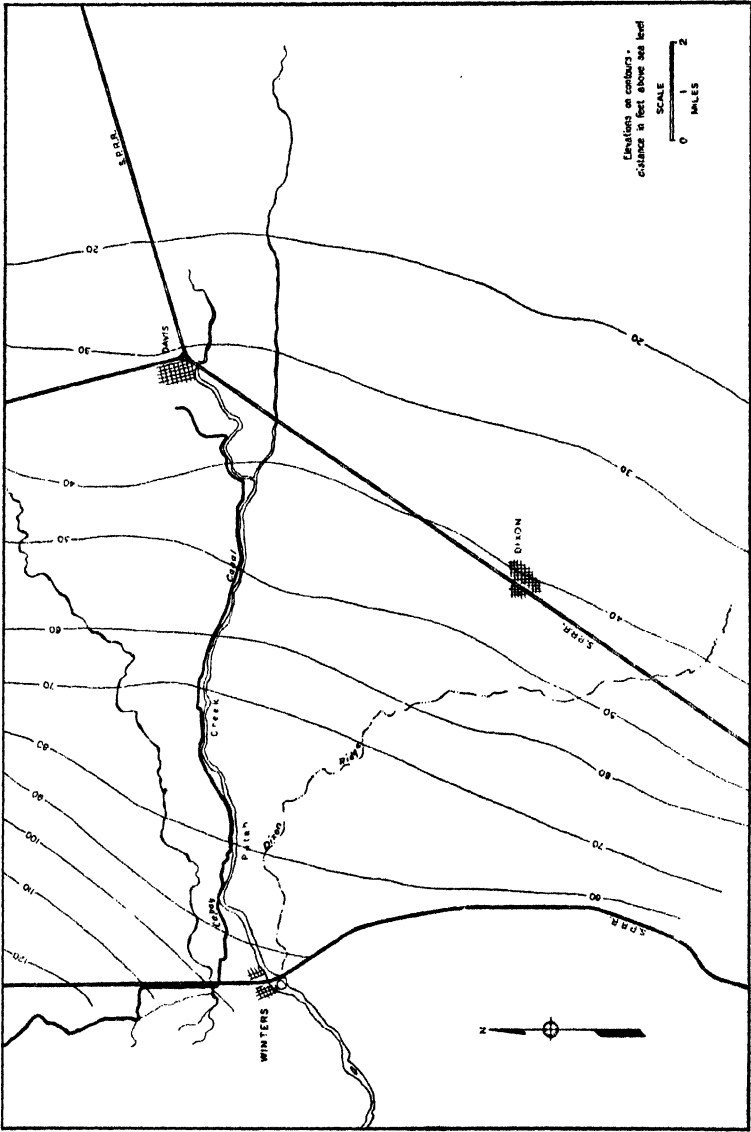


Fig. 4.—Underground water elevations on Putah Creek cone area as found by Bryan (2) in 1912.

Ground-Water Levels and Ground-Water Movement.—Water levels in the lower basin of Putah Creek were first studied in detail by Kirk Bryan (2) in 1912 during a comprehensive study of the underground water of Sacramento Valley. Figure 4 presents Bryan's findings for this area. As this figure shows, the slope of the water levels at that time was gradually up from the Sacramento River and the ground-water contours were parallel to that stream and at right angles to Putah Creek. Bryan reported 125 pumping plants in the Davis-Dixon-Winters area. Horizontal centrifugal pumps installed in shallow pits predominated. This type of equipment could be used economically because the depth to water was then about 20 feet. With continued pumping, water levels subsided materially, till a change from horizontal centrifugal to deep-well turbine pumps was required.

As early as 1922, the Irrigation Division undertook a study of water levels in shallow wells on the University Farm to determine whether the water table approached the ground surface closely enough to influence the results of irrigation experiments on orchard trees, as well as to be informed regarding the water table over the entire University Farm. According to observations of the first few years, the water levels lay beyond the rooting depth of most plants. Consequently, as these shallow wells caved they were not always recleaned. Subsequent notes on such wells did not report depth to water, but merely stated that it was below a certain depth.

Figure 5 shows the location of shallow and deep wells on the University Farm. Wells 1, 3, 4, 5, 6, and 9 are deep-irrigation wells.

Besides the shallow-well tests, water levels in University Farm irrigation well 1 have been recorded since 1912, supplemented, since 1931, with weekly records of levels in University Farm irrigation well 3. Since these records for both shallow and deep wells were taken at weekly to monthly intervals during some periods, they afford a means of comparing the behavior of deep and shallow wells.

Figure 6 indicates the elevation of waters in a selected group of typical shallow wells, together with those from deep wells 1 and 3. There are three items of interest: first, the different plane occupied by the water in deep well 1 as contrasted with all the shallow wells; second, that irrigation well 3 conforms in water elevation to the shallow wells and not to irrigation well 1; third, the tendency of water in shallow wells, and also in well 3, to rise and fall with the same frequency as in well 1 but slightly behind it in phase. The explanation for these three singularities appears to be as follows:

1. The downward-moving surface waters supplied by rains and irrigation cause the elevations of the water in shallow wells to be higher than

in the deep wells. That is, the deep-well water elevation results from water pressure within the water-bearing strata pierced by the well. This pressure is also present throughout the immediate area, which includes some shallow wells. Under static conditions where no outside influence

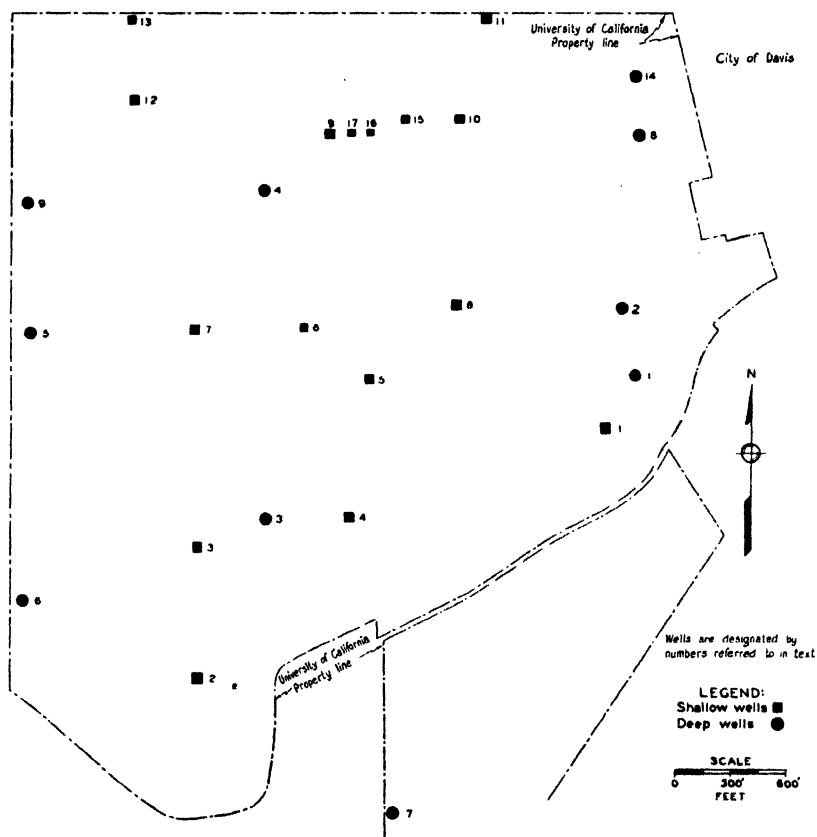


Fig. 5.—Shallow and deep wells on University grounds at Davis. The wells are designated by numbers referred to in the text.

(such as downward-moving surface water or pumping of deep wells) was present, the shallow wells would show the same water elevations as a nearby deep well. The difference in elevation of water surfaces between deep and shallow wells represents the friction head lost in moving existing flow from the water table of the shallow well to the aquifer supplying water to the deep well. In areas such as artesian basins, where water is moving upward, deep wells indicate higher water levels than nearby shallow wells (3, 4). Shallow wells show less marked fluctuations in the

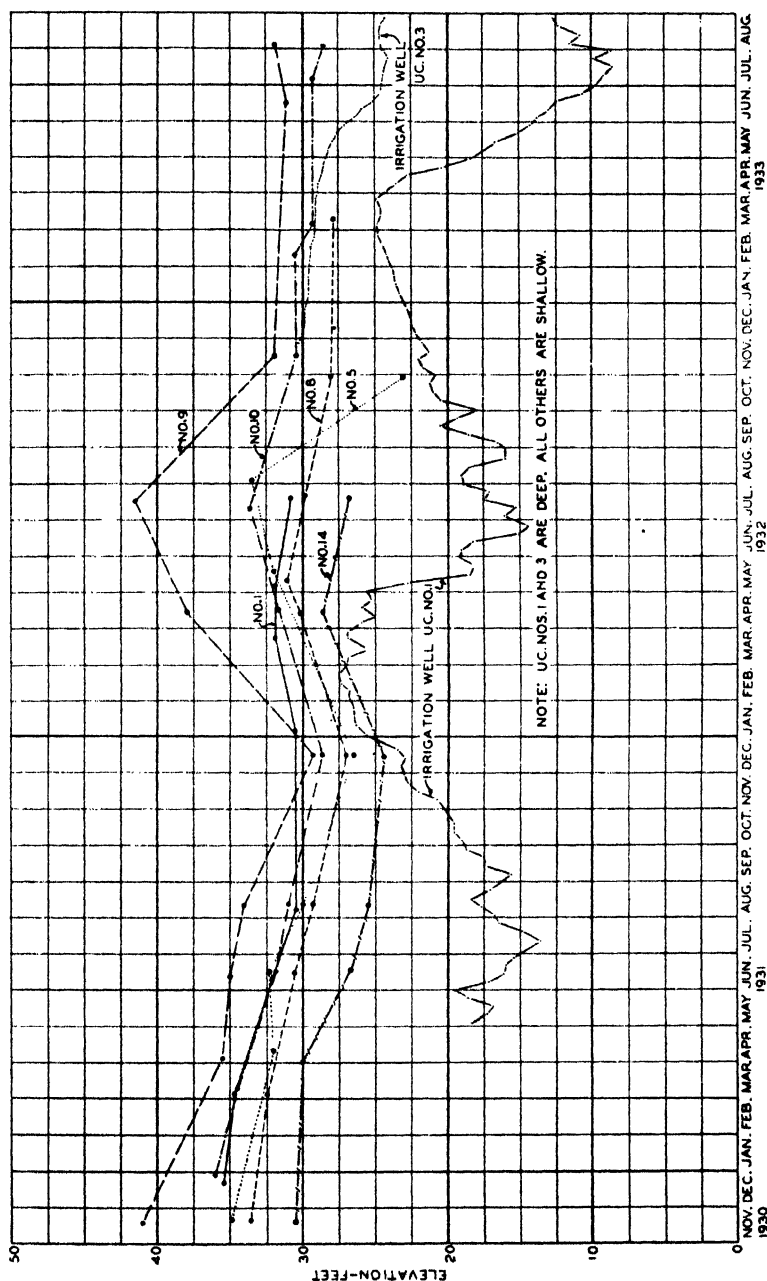


Fig. 6.—Seasonal water elevations from wells on University grounds for the years 1931 through 1933. Elevations are from sea level.

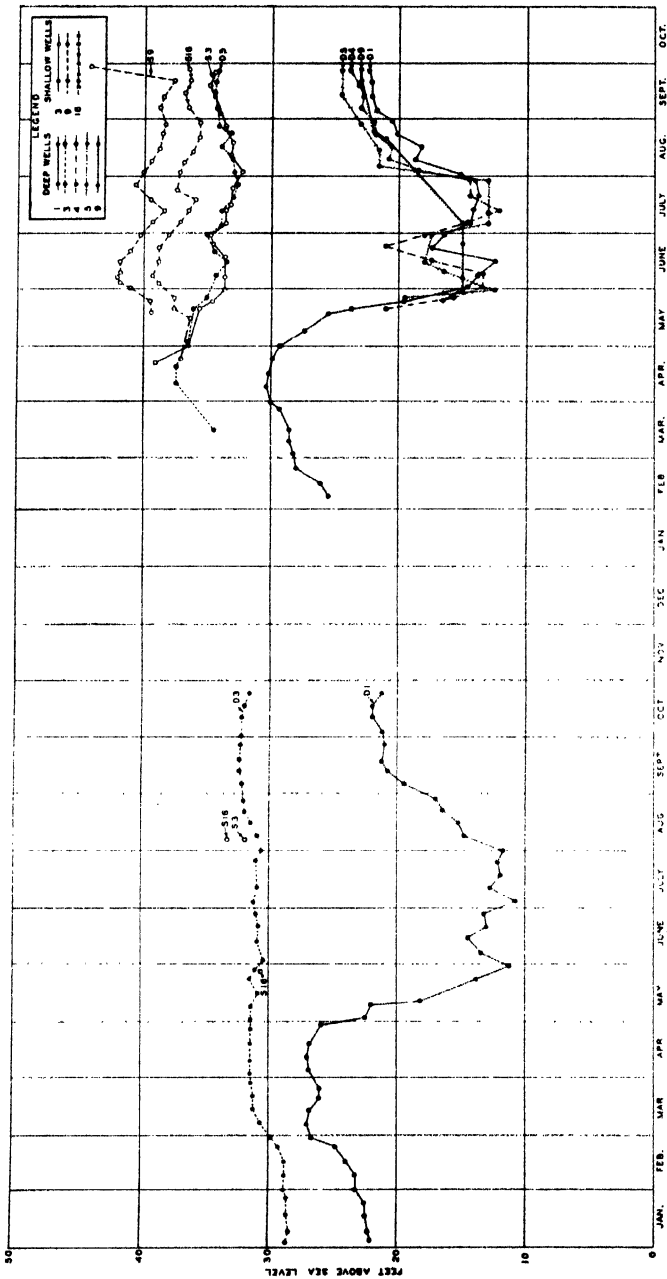


Fig. 7.—Seasonal water elevations from wells on University grounds during the years 1936 and 1937.
Data are missing from November 1936 to February 1937.

water level than deep ones because the relatively impermeable strata restrict flow, thereby retarding the transmission of pressure differences from the deep strata.

2. Irrigation well 3 conforms more closely to the shallow wells than to irrigation well 1, being an abandoned irrigation well whose lower strata have been sealed by use of a cement plug. As a result, well 3, although open to a depth of 125 feet below the soil surface receives its water from the shallow sources and not from the deep stratum it originally tapped. Figure 7, presented to identify further the characteristics of well 3, shows that the elevations of 1, 4, 5, and 9, all deep irrigation wells, behave similarly, while well 3 behaves like shallow wells on the University Farm. The fact that irrigation well 3 is typical of the shallow wells is fortunate in that one may gain a general idea of the trend of all of the shallow wells on the farm by studying its water-level records, which are for weekly intervals since 1931. This period is deficient in water-level records for shallow wells of the University Farm.

3. The lack of phase agreement between deep and shallow wells is caused by the resistance of the conducting medium to the flow of water. The fine-textured subsurface materials damp the magnitude of the deep-well-water-level cycle, and thus retard the phase of the water elevations in the shallow well.

Figure 8 shows the ground-water contour elevations in the lower basin derived from the data collected before the winter rains of 1931-32. Comparison of this graph with figure 4 shows a decided shift in ground-water elevations, the result of increased and long-continued pumping. Data for both shallow and deep wells obtained in the 1931 survey are plotted in figure 8. As the contours show, the subsurface water levels had been lowered most markedly about the town of Dixon, where a depression had been created. This survey came a month or so too late to get the maximum depression in the deep-well water levels that occurs in this area usually during September. Figure 8 shows a contraction of the contours along the Dixon ridge a few miles northwest of Dixon. This contraction evidences a decided change in underground-flow characteristics. Another interesting item in this figure is that water levels north of Winters are higher than those shown by Bryan. This condition may be explained by the importation of water from Cache Creek for irrigation into this area after Bryan's survey.

Figure 9 presents the contour elevations existing in the spring of 1932. By comparing these contours with those for December, 1931, one may discern a pronounced recovery of water levels in the Dixon area.

From the spring of 1932 through the spring of 1940, ground-water levels have been obtained in the fall about November 15 and in the spring

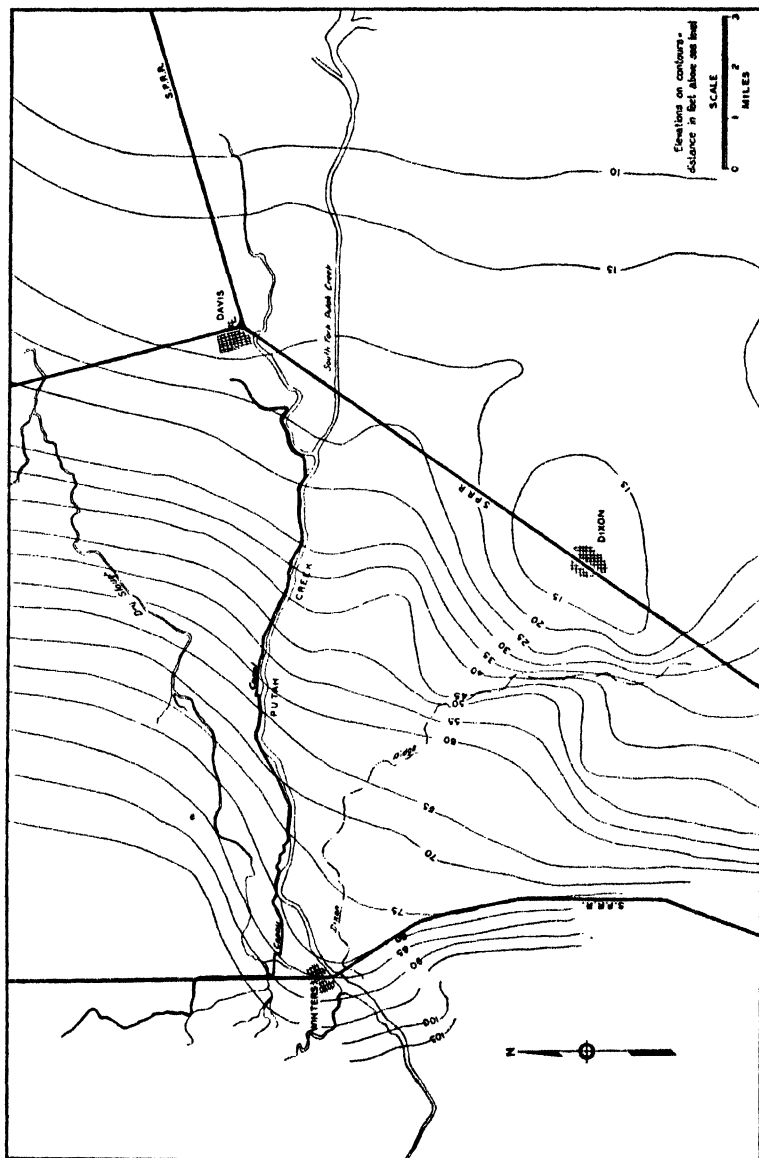


Fig. 8.—Underground water elevations on Putah Creek cone in December 1931.

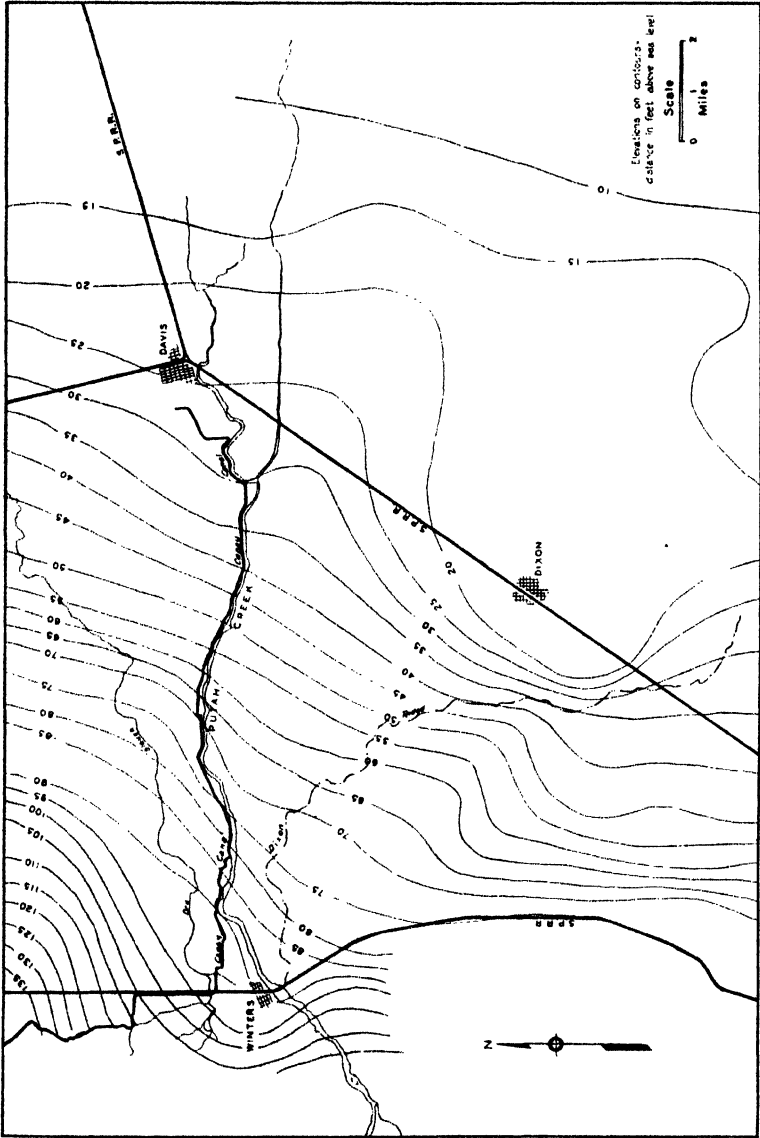


Fig. 9.—Underground water elevations on Putah Creek cone in the spring of 1932.

about April 15. Since the inaccessibility of certain wells made it impracticable to visit them regularly, a number have been dropped from the list. Unfortunately, the deep-well records are in the minority: few of these installations are so arranged as to permit access for measuring the water depth. This is a common fault of such installations and one most undesirable to the operator who wishes to keep informed of his pumping conditions.

Judging from season-to-season records of ground-water elevations, the depressed condition in the Dixon area has not become worse. Local spots about Davis have recently shown a depressed ground-water elevation. This situation can probably be explained by the large increase in pumping that has resulted from the recent development of previously unirrigated lands for the growing of sugar beets and tomatoes.

From this statement regarding the lowering of ground-water levels in the Dixon area, one might conclude that the territory was not experiencing a true overdraught to date. Seasonal shortages in water supply may, however, create unusual lowering of water tables. The return of normal precipitation brings the water levels back not to those found by Bryan in 1912, but to some intermediate plane. This plane is lower than that found by Bryan: flow in the underground strata encounters resistance; and unless there is an increase in the differential levels between the water source and the area where the water is used, there will be insufficient gradient to permit the necessary movement. The present water levels represent, then, the balance between supply and demand. The difference in water-table elevations between 1912 and 1931 represents the difference in head necessary to supply the 1931 pumping need as compared with the 1912 demand. This lowering of the water table does not indicate an overdraught, but rather is the ground water gradient necessary to meet increased pumping demands.

The discussion of deep and shallow well-water levels for the University Farm calls for an application of the same line of reasoning to the larger area—namely, the Putah Creek lower basin. If readings on the shallow wells of the University Farm differ from those on the deep wells, it might be assumed that readings from a miscellaneous collection of wells located throughout the basin might not present a true picture either. Figure 10 shows water-surface contours for both shallow and deep wells in the area for the fall of 1936, the dash lines representing elevations for deep wells, and the solid for shallow wells. Comparison of figure 11 with figure 10 reveals that the shallow wells, which are represented in greatest numbers, have governed the location of contours in figure 10. As previously noted, these data were obtained at the same time each year and may therefore be compared.

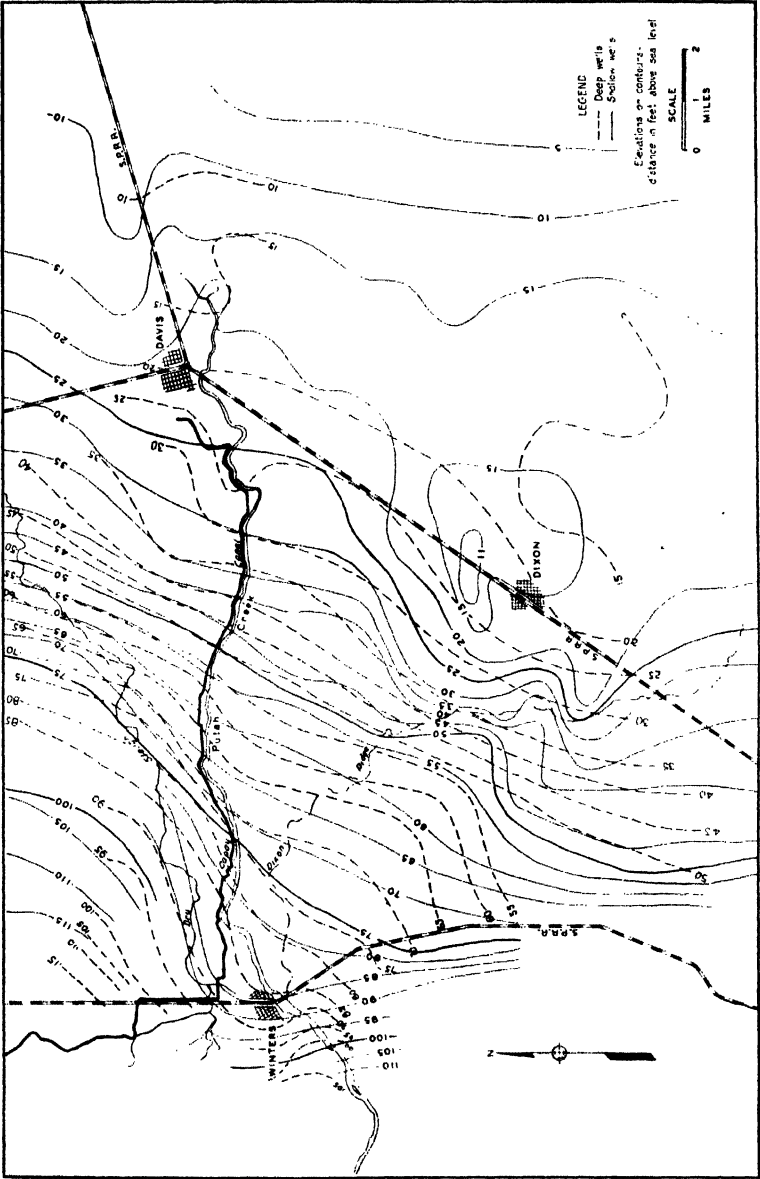


Fig. 10.—Underground water elevations on Putah Creek cone in the fall of 1936.

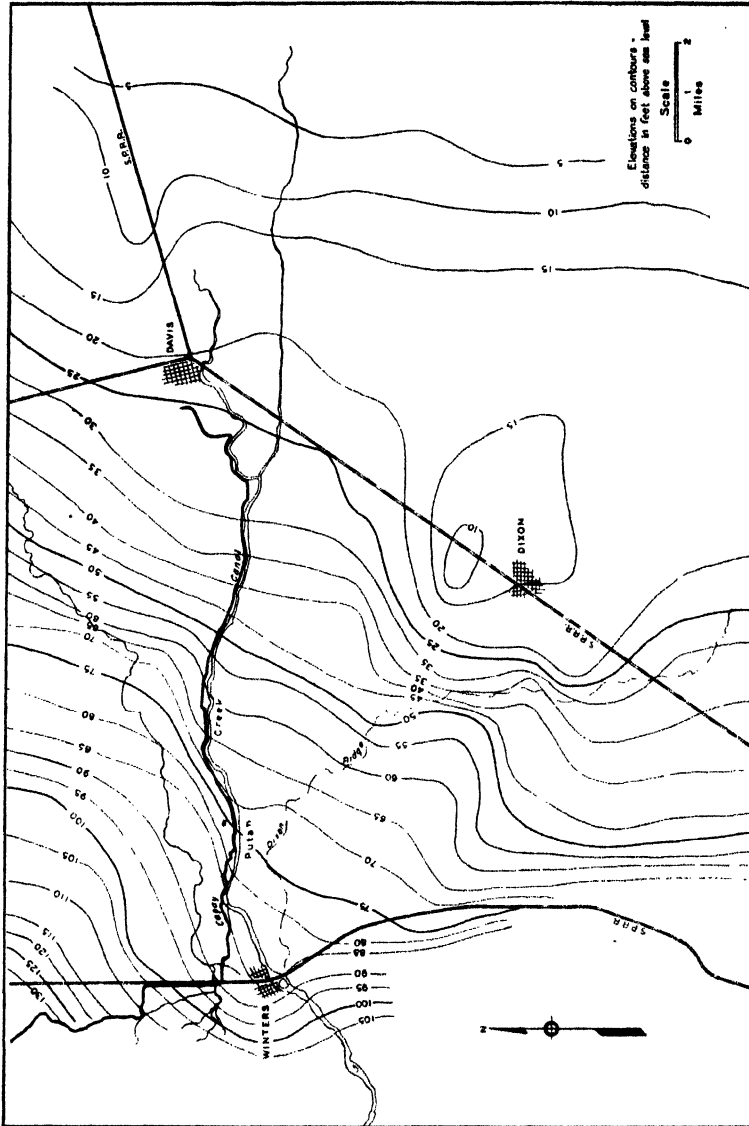


Fig. 11.—Underground water elevations on Putah Creek cone in the fall of 1936, using all deep and shallow well readings.

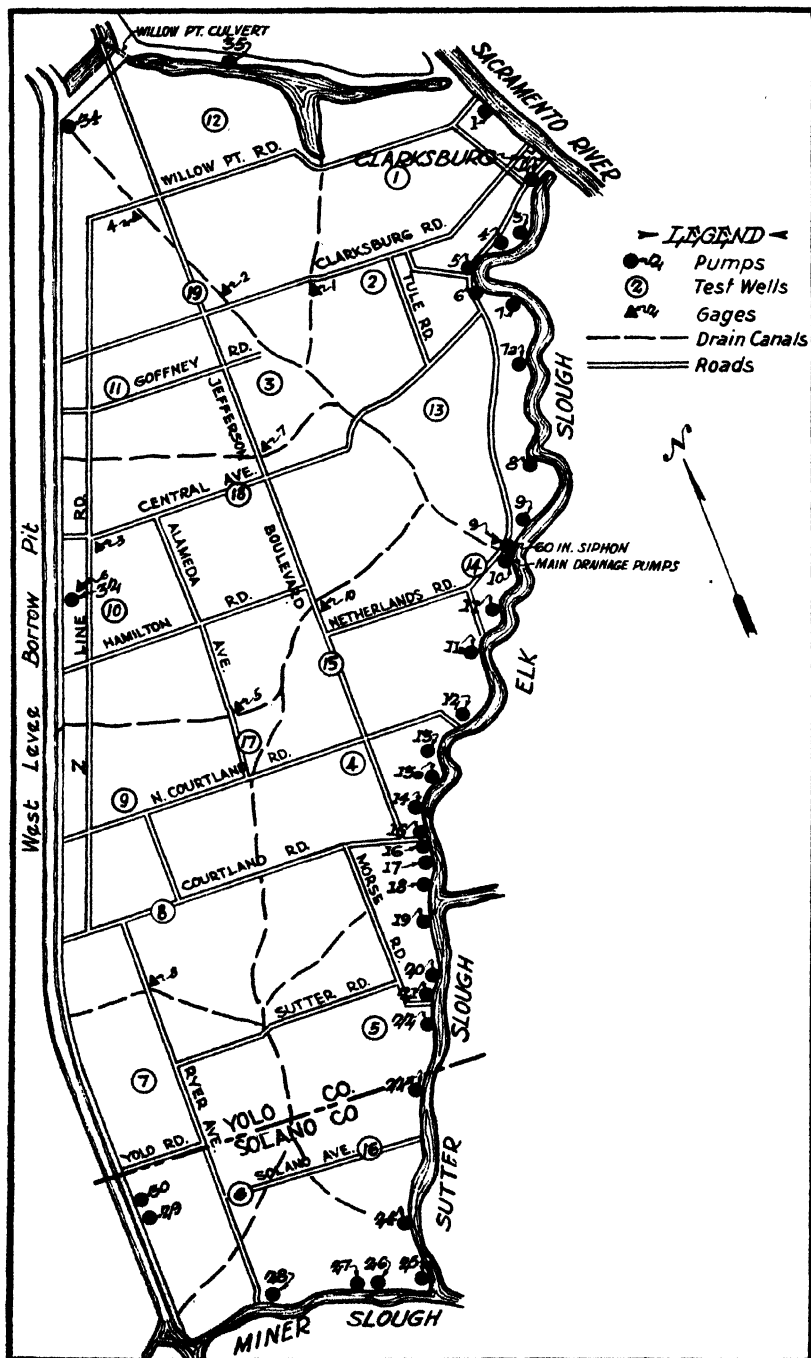


Fig. 12.—Reclamation District 999 in Sacramento Valley.

A related but slightly different set of conditions was encountered in a study instituted by the Irrigation Division during 1926 in Reclamation District 999 (fig. 12), a district which lies on the eastern edge of Putah Creek lower basin, adjoining the Sacramento River. It is a man-made island resulting from the construction of large drainage ditches and levees along its western and northern borders. The land within the island was below the Sacramento River water surface, particularly at high tide. Careful tests by the Slichter method (5), made along the levee banks within the island, showed no leakage through the banks.

TABLE 1

FREQUENCY DISTRIBUTION OF 133 PUMPING PLANTS, CLASSIFIED ACCORDING TO CAPACITIES AND EFFICIENCIES; PUTAH CREEK AREA, 1931*

Capacities, gallons per minute	Number of centrifugals	Number of turbines	Efficiencies, per cent	Number of centrifugals	Number of turbines
0- 99.....	1	1	5- 9.9.....	0	1
100- 199.....	17	3	10-14.9.....	0	0
200- 299.....	21	4	15-19.9.....	3	0
300- 399.....	13	8	20-24.9.....	11	1
400- 499.....	12	7	25-29.9.....	9	3
500- 599.....	9	7	30-34.9.....	15	11
600- 699.....	8	5	35-39.9.....	27	11
700- 799.....	3	4	40-44.9.....	13	12
800- 899.....	2	2	45-49.9.....	6	5
900- 999.....	3	2	50-54.9.....	3	0
1,000-1,099.....	0	1	55-59.9.....	2	0

* Mean pump discharges of centrifugals, 390 gallons per minute; of turbines, 500 gallons per minute. Mean pumping-plant efficiencies of centrifugals, 35 per cent; of turbines, 36.6 per cent. Pumping plant efficiency = $\frac{\text{horsepower output} \times 100}{\text{horsepower input}}$.

Seepage water was known to be entering the area, however, for the amount of drainage water pumped from the district exceeded the amount admitted through irrigation inlets. The construction of a series of 30-foot wells demonstrated that a very appreciable supply of water was entering the island at a depth of 20 or 30 feet below the ground surface. This water came through a sand and gravel layer extending from the river westward to the drainage canals across the island. As a result, the wells near the dikes surrounding the island flowed at high tide, and tidal effects were noted across the entire tract in diminishing degree and with retarded phase as the distance from the levee increased. In District 999 the tidal effect comes twice daily, whereas in the lower Putah Creek district, extremes of high and low water levels occur but once a year.

Pumps and Pumping Conditions.—The inventory taken during the fall of 1931 and spring of 1932 showed 301 pumping plants in Putah Creek lower basins. Of these pumps, 153 were turbines, 139 horizontal

centrifugal, 8 vertical centrifugal, and 1 direct flow. Eighty per cent of the pumps enumerated were driven by electric motors.

Mechanical tests were made on 133 pumping plants by the Division of Agriculture Engineering and Irrigation. These tests provided information on well sizes and depths, pump types and sizes, depth to static and pumping, water levels, suction lifts, discharge rates, and electrical power requirements. Tables 1 to 3 present some of these data.

TABLE 2
FREQUENCY DISTRIBUTION OF 133 PUMPING PLANTS, CLASSIFIED ACCORDING TO
SUCTION LIFTS, TOTAL PUMPING HEADS, AND MOTOR LOADINGS;
PUTAH CREEK AREA, 1931

Horizontal-centrifugal pumps, feet of suction height	Number of plants	Feet of pumping lift*	Number of centrifugals	Number of turbines	Per cent rated motor loadings†	Number of centrifugals	Number of turbines
5-9.9	2	25-29.9	1	1	50-59	5	0
10-14.9	6	30-34.9	3	0	60-69	4	0
15-19.9	18	35-39.9	7	2	70-79	14	2
20-24.9	36	40-44.9	14	3	80-89	13	3
25-29.9	21	45-49.9	20	11	90-99	21	2
30-up	6	50-54.9	15	4	100-109	16	10
		55-59.9	15	13	110-119	7	10
		60-64.9	9	2	120-129	4	8
		65-69.9	4	3	130-139	0	7
		70-74.9	1	3	140-149	3	1
		75-79.9	0	0	150-up	2	1
		80-84.9	0	1			
		85-89.9	0	0			
		90-94.9	0	1			

* Pumping lift as used here is the vertical distance between the water surface at the suction end of the pump to the water surface at the maximum height of delivery. Mean suction lift of centrifugal pumps, 21.8 feet. Mean pumping lift of centrifugals, 50 feet; of turbines, 55 feet.

† Mean per cent of rated motor loading of centrifugals, 93 per cent; of turbines, 113 per cent.

Characteristics of the Water-bearing Formations.—The study of water-bearing strata for the basin has been limited to information from well-drillers' files and to personal observation of well drilling. Unfortunately some of the data are not accurate, as the drillers have no standard of classification for materials encountered in drilling wells.

Because of lack of continuity in the water-bearing formation, drillers often fail to make contact with good gravels even when drilling near a successful well. Thicknesses of water-bearing strata in the area vary widely, ranging from 2 feet to as much as 60. A rather sharp break in water-strata levels is found on a line about halfway between Winters and Davis. Here the upper water-bearing stratum passes from about sea level on the Winters side to below sea level on the Davis side. This line is marked on the surface by the Plainfield Ridge (fig. 13) a conglomerate outcrop, which extends into the lower Putah Creek basin from

the northwest. At times this obstruction has doubtless acted as a dam, diverting the stream channel of Putah Creek and causing materials to be deposited on its eastern flank at elevations lower than they would have appeared had the stream been able to continue directly across the area.

The well log data determine roughly the position of the area in which gravels might be found as outcrops at the surface of the ground. Such an area, if present, would be found approximately where the soil-surface

TABLE 3

FREQUENCY DISTRIBUTION OF 133 PUMPING PLANTS, CLASSIFIED ACCORDING TO HOURS OF PUMP OPERATION; PUTAH CREEK BASIN, 1931

Hours of operation per year*	Number of centrifugals	Number of turbines
0- 100.....	3	3
200- 300.....	12	4
400- 500.....	12	6
600- 700.....	12	8
800- 900.....	10	5
1,000-1,100.....	6	6
1,200-1,300.....	7	2
1,400-1,500.....	6	5
1,600-1,700.....	4	3
1,800-1,900.....	5	2
2,000-2,100.....	2	0
2,200-2,300.....	1	0
2,400-2,500.....	1	0
2,600-2,700.....	3	0
2,800-2,900.....	2	0
3,000-up.....	3	0

* Mean hours of operation for centrifugals, 1,165; for turbines, 945.

profile coincides in elevation with that of the actual, or projected, profile of the upper surface of the water-bearing gravels. This area would be close to the head of the lower basin. According to figure 13, such an area should be found west of Winters. This supposition checks with the facts.

The finding of extreme variations in thickness of water-bearing strata raises the question of yield and makes one wonder how the thickness of strata pierced by a given well affects the output. As previously noted, many wells were tested during the fall of 1931 and the spring of 1932. These tests gave information on discharge and drawdown (difference between static and pumping-well water levels), but the data revealed no direct relation between drawdown and stratum thickness as determined from the well logs.

If the portion of Putah Creek below Winters were a direct factor in supplying the wells, the specific yield, or discharge per unit drawdown, might be expected to be larger near the creek bed than at a distance. This supposition is not borne out by the data. In general the wells along the

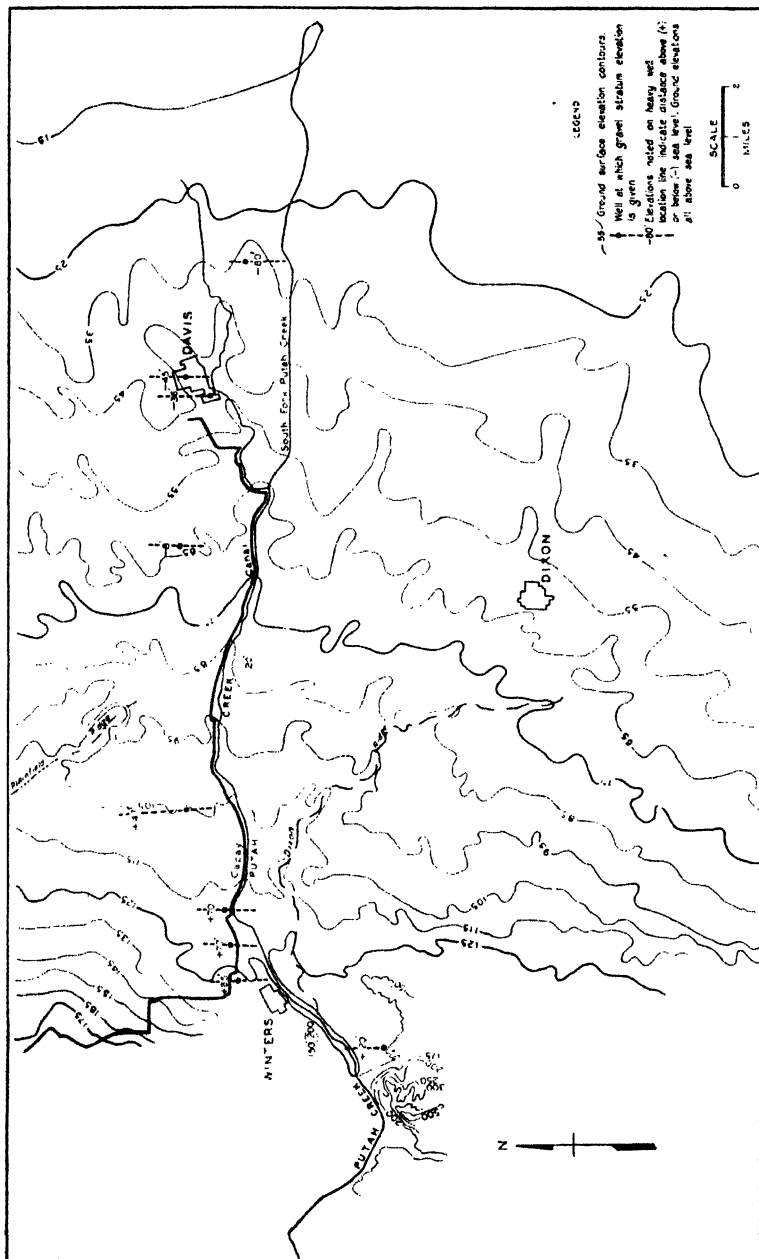


Fig. 13.—Elevations of soil surface and top of first gravel stratum on Putah Creek cone.

creek below Winters obtain their supply not from the immediate creek bed but through the water-bearing strata that tap the bed at some distance upstream.

Water Temperatures.—The temperature of the underground water is remarkably uniform, ranging from 64° to 66° F and averaging about 65°. Only one or two very deep wells give readings a few degrees higher than the average. This should be of interest to those who are interested in using air conditioning in connection with houses in this area.

TABLE 4
FLOW AND BORON CONTENT OF CACHE CREEK AND PUTAH
CREEK WATERS*

Stream and sampling date	Flow, cubic feet per second	Boron content, parts per million
<i>Cache Creek:</i>		
December 5, 1934.....	150	1.02
December 30, 1934.....	200	6.44
February 1, 1935.....	510	1.45
March 4, 1935.....	890	1.15
May 3, 1935.....	350	1.08
June 2, 1935.....	370	2.10
July 8, 1935.....	224	2.34
August 1, 1935.....	172	2.23
September 5, 1935.....	131	2.46
<i>Putah Creek:</i>		
February 28, 1939.....	...	0.0
March 11, 1939.....	...	Trace

* Samples from Cache Creek, collected by W. D. Norton, Farm Advisor, Yolo County; analysis by United States Division of Western Irrigation, Rubidoux Laboratory, Riverside.

Boron as a Water Source Indicator.—In contrast with the uniformity of the water temperatures, there is a wide divergence in the boron content of the well waters. The data on this point are reported in tabular form in the paper by Bisson and Huberty (1).

As the presence of boron affords a possible means of tracing the direction of flow of underground water, supplementary data were obtained from the Cache Creek basin. The waters of Cache Creek, the next stream to the north and above Putah Creek, were known to be relatively high in boron, whereas Putah Creek was known to carry but little boron. Table 4 indicates the character of the waters from the two sources—one consistently high, the other low in boron.

If wells in the Putah Creek basin were to contain relatively high amounts of boron, one might assume that water from Cache Creek was entering the underground aquifers either artificially, via Capay Canal, or naturally. Judging from table 5, the canal and the ditches branching

from it might directly influence the character of well waters. Wells above and west of the main canal showed little or no influence of the canal water, whereas the well below the canal was markedly affected. A well in permeable material immediately adjacent to a ditch (like well F) will have water similar in composition to the ditch water.

In an area about 4 miles east of Davis are several wells with water of high boron content. This is in an area where the fans of Cache and Putah Creeks merge. Those wells which are influenced by Cache Creek will have a higher boron content than those dependent upon Putah Creek.

TABLE 5
BORON CONTENT OF WELL WATERS IN RELATION TO CAPAY CANAL

Well designation and location	Date of sampling	K 10 ^s at 18° C	Boron, parts per million*
A; canal.....	Nov. 4, 1937	59	2.97
B; well above canal, 50 feet west.....	Nov. 4, 1937	56	0.21
C; well above canal, ¼ mile west.....	Nov. 4, 1937	32	0.11
D; well above canal, 1½ miles west.....	Nov. 4, 1937	42	0.07
E; well below canal, ¼ mile west.....	Nov. 4, 1937	60	1.14
	Jan. 7, 1936	..	1.9
	Jan. 11, 1936	..	1.75
F; well at ditch bank.....	Jan. 28, 1936	..	1.61
	Aug. 20, 1936	..	1.65
	June 3, 1937	..	1.43
	Aug. 9, 1937	..	1.69
Ditch.....	May 23, 1936	..	1.74

* Analysis by Carl Hansen, Division of Pomology.

Relation of Drawdown to Discharge in Wells.—The drawdown-discharge curve for a well is obtained by plotting as coördinates the drawdown and corresponding discharge at any given time. If this point is joined by a straight line with the point of zero drawdown and zero flow, the drawdown for any intermediate discharge is located. This same line, if extended, will indicate fairly accurately the relative drawdown-to-discharge rate until the drawdown starts to uncover the upper porous water-bearing stratum tapped by the well. Since the drawdown-discharge relation holds for a single well, it might hold for a group of wells in restricted territory like that around Dixon. In other words, a given seasonal pumping load should cause a given drawdown or reduction in water levels. A rough approximation of the pumping load exists in the electric-power demand for irrigation in the area. The monthly power-consumption records for the vicinity of Dixon show 3 or 4 months during the winter when the demand is much lower than for the summer. The increase in power use corresponds to the sudden lowering of water levels in the spring; the decrease in power use, to the initial recovery of water levels in the fall.

In order to determine the amount of electrical energy devoted to irrigation pumping we may assume that the average monthly winter load is more or less constant and that we may deduct this amount from the monthly summer load. The sum of the net monthly pumping loads for the irrigation season will then constitute the seasonal power consumption.

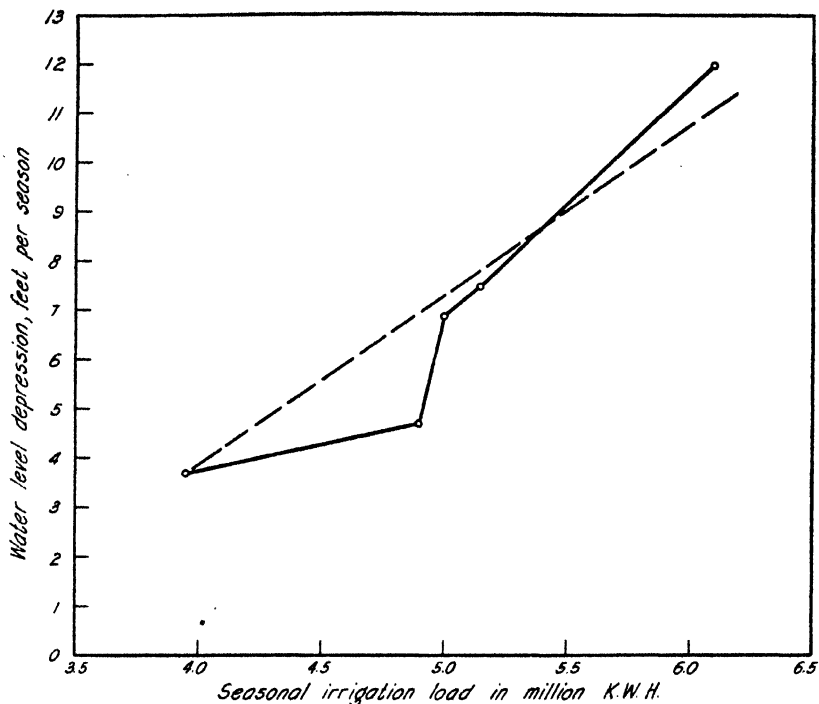


Fig. 14.—Relation between irrigation power demand and seasonal water level depression for Dixon area on Putah Creek cone.

Dash line is rough average.

Figure 14, showing the result of plotting these yearly irrigation power loads against the corresponding drawdown for the area, indicates a direct relation between these factors for the Dixon area.

Recharge of Ground-Water Basin.—Stream flow in the lower basin depends upon the amount and the intensity of precipitation for there are no storage reservoirs in Putah Creek to regulate flow. This flow varies from a maximum of almost 60,000 cubic feet per second for short periods after heavy storms to nearly zero during the summer. A minimum stream flow of 4 or 5 cubic feet per second passes from the upper to the lower basin throughout the summer, but it soon disappears in the porous gravels of the lower basin. Normally no water passes the town of

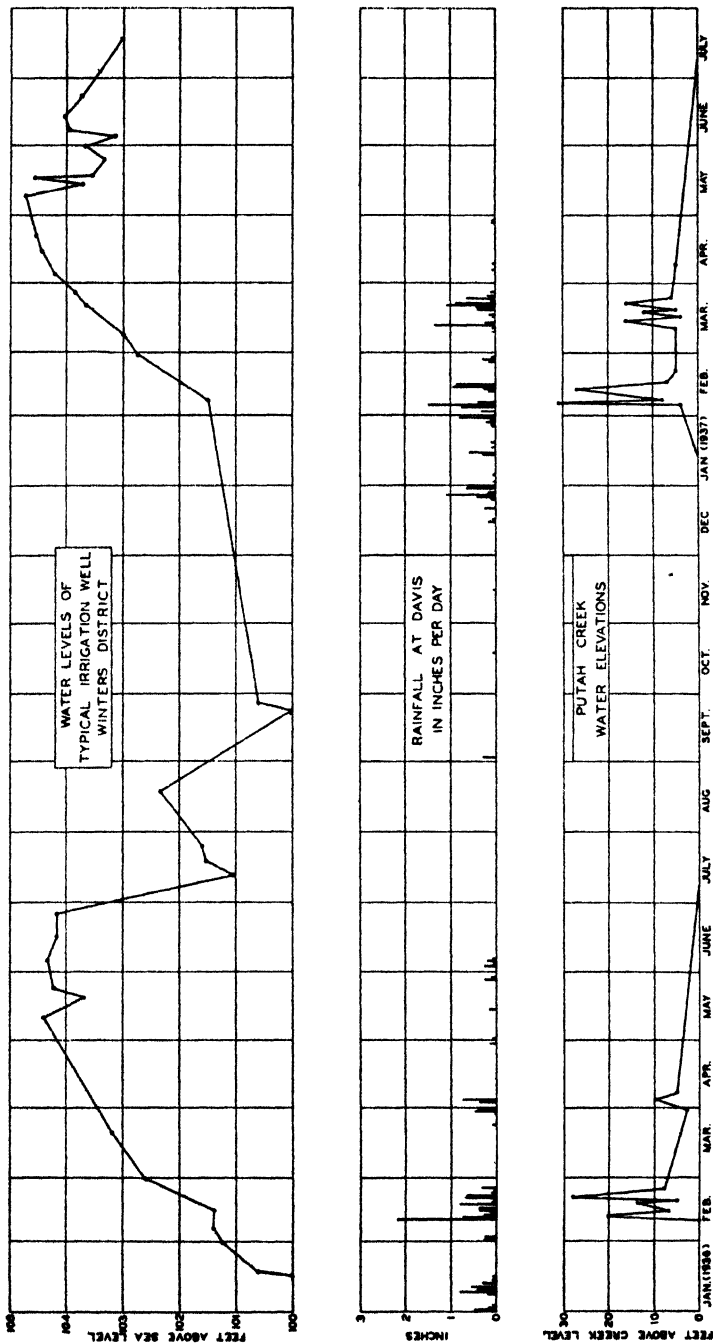


Fig. 15.—Relation between rainfall, streamflow, and well-water level for Putah Creek cone in 1936 and 1937.

Winters after July 1, percolation into the porous underground strata being at such a rate as to absorb the entire flow. That this supply does not suffice to maintain water levels even in the immediate vicinity is indicated by the lowering of levels during the pumping season.

Figure 15 portrays the rainfall and the flow in Putah Creek for 1936, showing that peaks in creek flow follow peaks in rainfall. The recovery of water levels in wells is influenced also by the presence of peak flows in the stream. As figure 15 shows, a high water crest in the creek is followed by an accelerated rise of water in the wells. This increased rate of infiltration lasts for a week or two and then subsides until a succeeding flood crest causes a further acceleration—a phenomenon indicating the close relation between stream flow and underground water supply. The lag between stream and well crests depends upon the resistance of the strata to the passage of water.

SUMMARY

Deep wells in the Putah Creek lower basin should be differentiated from shallow wells when one is studying water supplies and water tables. Although the latter wells are affected by the former, their water-level fluctuations are in general out of phase with the deeper well levels, and they normally have higher water elevations than the deep wells near by. In certain areas, such as Reclamation District 999, where shallow water strata are under pressure, the surface layers may receive some water from the pressure-bearing strata below.

Most of the ground-water supply of Putah Creek lower basin enters through the porous gravel beds near the head of the fan, in the vicinity of Winters. This finding is borne out by the accelerated recoveries of wells adjacent to the creek immediately after flood periods. This area is potentially a great spreading basin.

The boron content of the well waters varies widely. Cache Creek water imported into the district has had a marked influence upon some well waters. The data secured indicate a possible method of studying underground water movements.

The underground water temperatures are uniform throughout the basin for all but the deepest wells, which tend to be several degrees warmer than the others.

Although underground water levels in the area north of Winters have been raised since 1912 by the use of the Capay Canal water, other parts of the area have had drops in water levels of 15 to 25 feet during the period. This lowering does not represent an overdrought, but rather the changes in head resulting from increased pumping. In dry periods, the recession is greater than usual; the recharge is good during years of normal or above-normal rainfall.

ACKNOWLEDGMENTS

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**CHEMICAL COMPOSITION OF WATER IN
THE PUTAH CREEK BASIN**

C. S. BISSON AND MARTIN R. HUBERTY

CHEMICAL COMPOSITION OF WATER IN THE PUTAH CREEK BASIN¹

C. S. BISSON² AND MARTIN R. HUBERTY³

INTRODUCTION

CONCURRENTLY with the 1931-1932 hydrologic investigation of Putah Creek basin, reported by Huberty and Johnston in the accompanying paper (3),⁴ studies of water quality were being made.⁵ The purpose of the study was to determine, from analytical data, the classification of waters of the area as to their chemical composition; the seasonal variation in the character and amount of dissolved salts; and to determine the boron content of the waters, since this element is highly toxic to most plants when present even in minute quantities (1, 2, 4).

METHODS OF PROCEDURE

Samples were obtained from the pump discharge of wells penetrating water-bearing formations of various depths. Figure 1 shows the locations of the wells, from which water samples were collected in glass-stoppered bottles for analysis. From a small number of wells, perforated at only one water-bearing stratum, water samples were collected at intervals of from one day to one week to determine the seasonal variation in salt content.

Water samples of from 2 to 4 liters, collected in glass-stoppered bottles were placed in wooden containers and immediately taken to the laboratory where determinations were made for pH, bicarbonate, carbon dioxide, and nitrate. Later analyses were made for calcium, magnesium, sodium, potassium, iron, carbonate, sulfate, chloride, phosphate, nitrate, silicon, aluminum, and boron. The total solids were determined at 105° C.

RESULTS OF THE ANALYSES

The results of the determinations of bicarbonate and chloride ions on samples collected to show seasonal changes in the dissolved salt content are recorded in table 1. Table 2 contains the analyses of well waters obtained within Putah Creek lower basin, and the results are reported

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⁴ Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

⁵ Dr. Walter Dye, former analyst for the Division of Chemistry, made the analyses.

in parts per million. The pH values reported in the second column were obtained soon after the samples reached the laboratory. For the convenience of those not accustomed to interpreting water analysis in parts per million, table 3 is introduced. Table 4 shows the values in table 2 tabulated according to depth of perforation, and table 5 gives the results for boron.

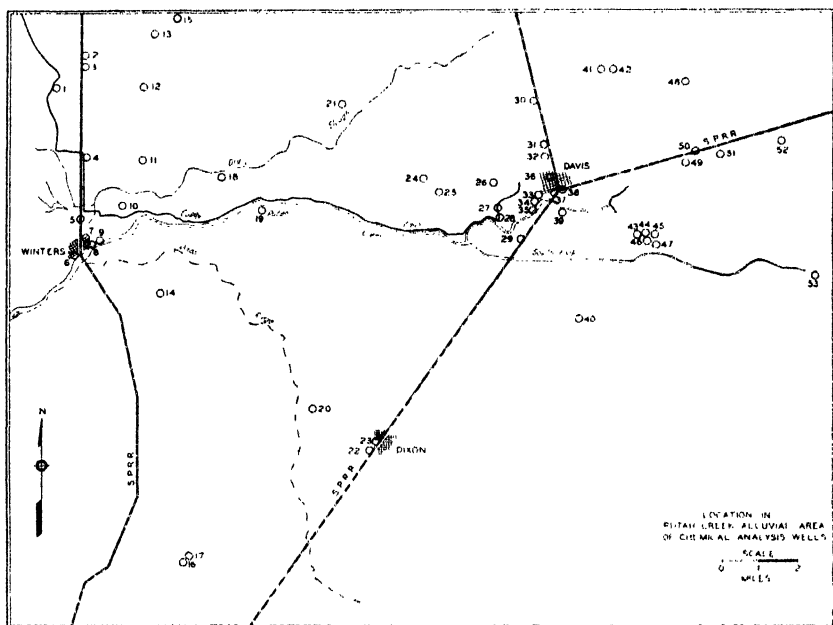


Fig. 1.—Location of wells in Putah Creek lower basin from which water samples for chemical analysis were obtained.

Concentration of Bicarbonate and Chloride Ions at Various Dates of Sampling.—Table 1 shows the bicarbonate and chloride content of well-water samples collected at short intervals of time. Samples from wells perforated at a single stratum within the depth range of 137 to 420 feet are remarkably constant with respect to these two ions. A well whose casing was perforated at several strata shows a considerable variation from day to day, which is very likely owing to a change in the relative amounts of water of different composition drawn from each stratum. Well no. 34, which is perforated at a single stratum, is a good example of wells showing remarkably constant composition with respect to these two radicals. Well no. 35, having more than one perforation, however, is a good example of wells showing considerable variation in composition. Table 3 furnishes additional proof that other chemical constituents are fairly constant in well water from single-stratum wells.

Composition of the Ground Waters.—Tables 2 and 3 show the results of analyses of samples from thirty-three wells in the area investigated, expressed in parts per million, and in milliequivalents per liter respectively. The hardness of nearly all these waters is of the bicarbonate type. This indicates that there is enough bicarbonate present to precipitate

TABLE 1
SEASONAL CHANGES IN CARBONATE AND CHLORIDE OF NUMBERED WELLS,
EXPRESSED IN PARTS PER MILLION*

Date	No. 27		No. 28		No. 34		No. 35†	
	HCO ₃ ⁻	Cl ⁻	HCO ₃ ⁻	Cl ⁻	HCO ₃ ⁻	Cl ⁻	HCO ₃ ⁻	Cl ⁻
<i>1931:</i>								
June 30.....	467	13.1	373	7.5	.....	.....	393	37.0
July 30.....	470	12.5	377	8.6	378	13.3	520	27.3
September 18.....	468	13.0	370	8.0	374	11.2	568	34.0
September 19.....	.....	.....	.....	.....	375	11.2	.....	.....
September 21.....	.....	.....	.....	.....	375	10.8	.....	.....
September 22.....	.....	.....	.....	.....	375	10.6	.....	.....
September 23.....	.....	.....	.....	.....	375	11.5	560	32.8
September 26.....	468	12.8	371	8.3	378	12.6	604	39.2
September 29.....	467	13.2	373	8.7	374	13.2	.....	.....
October 1.....	.....	.....	372	10.0	376	13.1	415	27.5
October 3.....	466	13.4	373	9.3	375	12.1	.....	.....
October 6.....	468	14.1	372	9.6	.....	.....	.....	.....
October 8.....	470	13.9	380	9.6	375	12.0	.....	.....
October 10.....	468	12.1	369	9.0	375	13.3	.....	.....
October 12.....	469	13.8	372	9.4	375	12.5	.....	.....
October 15.....	.....	.....	373	9.5	375	11.9	.....	.....
October 17.....	470	13.2	372	9.3	.....	.....	.....	.....
October 23.....	.....	.....	.....	.....	375	12.0	.....	.....
October 30.....	.....	.....	376	9.4	.....	.....	.....	.....
December 21.....	.....	.....	.....	.....	377	.....	.....	.....
<i>1932:</i>								
January 12.....	.....	.....	.....	.....	375	12.0	.....	.....
January 23.....	.....	.....	.....	.....	377	11.4	.....	.....
January 30.....	.....	.....	.....	.....	375	11.7	.....	.....

* With HCO₃⁻, the average deviation between check analysis is 1 p.p.m., and the maximum deviation, 3 p.p.m. With Cl⁻, the average deviation between check analysis is 0.2 p.p.m., and the maximum deviation, 0.6 p.p.m.

† Well 35 is perforated at more than one stratum.

the calcium on heating; the addition of lime should precipitate the remaining magnesium and bicarbonate. Well no. 43, the deepest well in the basin (1,030 feet), has the softest water, its hardness being 65 p.p.m. of Ca and Mg calculated as CaCO₃. The water from University Farm domestic well, no. 34, and the City of Davis, no. 37, with 255 and 135 p.p.m., respectively, would be called moderately hard. The iron content of the waters of the area is low, as is the nitrogen content, with three interesting exceptions namely, wells 45, 46, and 47. The shallow well, no.

TABLE 2
COMPOSITION OF WELL WATERS IN PUTAH CREEK BASIN EXPRESSED IN PARTS PER MILLION*

Well no.	pH	Cations						Anions				Total solids at 105°C	SiO ₂	CO ₂	Date (1931)
		Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Fe ⁺⁺ or Fe ⁺⁺⁺	HCO ₃ ⁻	SO ₄ ⁻	NO ₃ ⁻	Cl ⁻	Al as H ₂ AlO ₄ ⁻				
6.....	8.4	34	48	23	0.0	0.03-0.05	328	22	10	16	3.2	374	38	16	Aug. 6
6.....	7.9	30	45	22	0.5-1.0	0.03-0.10	308	23	..	19	2.4	347	40	24	Dec. 17
7.....	8.0	35	40	10	1.0	0.0-0.03	291	24	2	10	3.0	318	41	11	Aug. 6
8.....	8.3	34	64	23	0.0	0.0-0.03	385	31	15	25	2.3	450	..	20	Aug. 6
9.....	8.4	38	56	24	0.0	0.0-0.03	358	40	8	17	1.3	414	43	11	Aug. 6
16.....	8.7	33	86	61	.....	0.03-0.04	268	20	0	8	1.3	300	27	12	Sept. 25
17.....	8.5	30	15	42	.....	0.01-0.02	216	8	6	18	2.3	300	62	10	Sept. 25
18.....	7.7	33	33	48	0.0	0.0-0.03	254	38	3	37	2.7	361	38	10	Aug. 6
19.....	8.3	38	42	48	.....	0.01-0.02	..	47	2	45	2.0	415	39	12	Sept. 18
22.....	8.7	47	63	42	.....	0.0-0.04	467	28	19	21	1.7	500	40	25	Sept. 25
23.....	8.1	44	59	40	0.5-1.0	0.05-0.08	453	26	..	20	3.2	485	37	57	Dec. 17
23.....	8.7	21	24	47	.....	0.01-0.02	258	26	..	12	1.4	300	33	10	Sept. 25
24.....	7.7	35	68	53	0.0	0.0-0.03	438	30	5	20	2.7	504	41	17	Aug. 6
25.....	8.4	34	61	66	0.5-1.0	.....	476	29	5	13	6.1	467	38	10	July 31
26.....	7.9	25	51	53	0.0	0.04-0.08	393	40	0	14	2.4	403	30	8	Aug. 6
27.....	8.8	36	62	53	0.5-1.0	.....	459	40	3	13	5.6	492	41	0	June 30
27.....	8.6	36	60	50	0.0	.....	471	39	4	12	2.6	494	38	9	July 30
27.....	8.5	31	62	59	0.5-1.0	0.02-0.04	468	22	5	13	3.2	488	36	27	Sept. 18
28.....	8.6	22	44	45	0.5-1.0	.....	373	23	3	8	2.1	377	34	4	June 30
28.....	8.7	31	54	46	0.5-1.0	.....	378	22	3	9	4.1	447	49	5	July 30
28.....	8.4	29	45	44	0.5-1.0	0.02-0.03	369	23	3	8	3.3	373	33	13	Sept. 18
31.....	8.5	25	63	71†	.....	.....	460	60	1	21	6.1	505	38	15	July 30
32.....	8.9	26	101	131†	.....	0.0-0.02	680	114	6	55	3.8	832	32	18	Aug. 17
32.....	8.7	25	91	115†	.....	0.02-0.03	630	92	4	45	5.6	789	34	22	Aug. 17
33.....	8.9	28	49	48	0.0	0.04-0.08	385	34	3	13	3.0	407	40	8	July 31
34.....	8.9	29	45	52	0.0	.....	371	30	3	13	4.1	394	48	0	July 30
34.....	8.5	25	47	47	.....	0.01-0.02	375	35	0	11	2.1	390	35	12	Sept. 18
34.....	8.2	24	46	45	0.5-1.0	0.0-0.02	377	27	..	11	4.9	384	33	23	Dec. 17
35.....	8.3	26	62	93	0.5-1.0	.....	393	99	5	37	4.1	774	36	16	June 30

35	8.6	38	75	71	0.0	.....	520	71	3	27	3.2	602	38	10	July 30
35	8.7	42	86	80	0.5-1.0	0.0-0.02	568	88	4	34	6.1	688	37	26	Sept. 18
36	8.9	24	69	62	0.0	0.04-0.05	418	52	3	26	4.0	479	40	13	July 31
37	8.1	15	23	57	0.5-1.0	0.0-0.02	258	38	..	10	..	288	..	0	Aug. 28
37	8.3	19	23	68†	0.5-1.0	0.01-0.02	274	25	..	12	1.7	321	29	7	Oct. 13
37	7.6	15	22	57	0.5-1.0	0.06-0.10	272	25	..	11	5.2	293	30	5	Dec. 17
38	8.7	26	46	53	0.5-1.0	0.04-0.08	373	73	3	12	2.9	399	34	10	July 31
38	8.5	24	46	50	.....	0.02-0.04	365	30	2	12	1.8	374	35	13	Sept. 18
38	7.9	23	44	49	0.5-1.0	0.04-0.05	373	28	..	12	4.7	372	34	34	Dec. 22
39	8.9	34	74	76†	.....	0.02-0.03	540	67	5	24	2.4	598	38	12	Aug. 3
40	8.3	25	68	44	0.5-1.0	0.0-0.02	470	28	1	12	3.8	438	40	16	Aug. 7
43	8.6	16	6	97	0.0	.....	251	35	0	18	3.0	349	56	0	Aug. 1
45	8.6	33	118	66	0.0	.....	625	65	136	10	5.6	592	38	16	July 30
46	8.3	39	89	70	0.0	.....	584	64	8	27	5.6	668	38	13	June 30
47	8.3	44	97	34†	.....	.....	544	77	20	30	2.0	732	35	16	July 30
49	8.5	19	53	96	0.0	.....	387	66	0	32	4.1	405	56	5	June 30
51	8.4	22	45	70	0.0	.....	368	43	0	26	4.1	436	39	7	June 30
52	8.2	19	62	98	0.0	0.02-0.03	438	92	0	37	2.7	579	34	18	Aug. 7
53	8.5	25	51	63	0.5-1.0	.....	358	57	0	28	5.6	782	42	3	June 30
53	8.5	26	52	60†	0.0	0.04-0.08	362	65	1	29	3.0	447	43	8	July 31

* Phosphorus (as PO_4^{--}) was less than 1.0 p.p.m. in all samples. Carbonate (as CO_3^{--}) was less than 0.5 p.p.m. for all samples except in the case of well no. 43, which had 6 p.p.m.

† Calculated.

TABLE 3
COMPOSITION OF WELL WATERS IN PUTAH CREEK BASIN EXPRESSED IN MILLIEQUIVALENTS PER LITER

Well no.	Cations			Anions				Percent			Date (1931)
	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	HCO ₃ ⁻	SO ₄ ⁻⁻	Cl ⁻	NO ₃ ⁻	H ₂ AlO ₄ ⁻	Na	Ca	Mg
6.....	1.7	4.0	1.0	5.38	0.45	0.45	0.17	0.08	15	25	60
6.....	1.5	3.7	1.0	5.05	0.43	0.53	....	0.06	16	24	60
7.....	1.7	3.3	0.8	4.77	0.49	0.30	0.03	0.08	14	29	57
8.....	1.9	5.3	1.0	6.31	0.64	0.70	0.24	0.06	12	23	65
9.....	1.9	4.6	1.0	5.87	0.84	0.49	0.13	0.04	13	25	61
16.....	1.6	0.7	2.7	4.40	0.41	0.22	....	0.04	54	32	14
17.....	1.5	1.3	1.8	3.54	0.16	0.51	0.10	0.06	39	33	28
18.....	1.7	2.7	2.1	4.16	0.80	1.04	0.05	0.07	32	26	41
19.....	1.9	3.4	2.1	....	0.93	1.31	0.03	0.05	28	26	46
22.....	2.4	5.2	1.8	7.66	0.59	0.58	0.30	0.04	19	26	55
23.....	2.2	4.9	1.7	7.43	0.54	0.56	....	0.08	19	25	56
23.....	1.0	2.0	2.0	4.23	0.54	0.54	....	0.04	40	20	40
24.....	1.8	5.6	2.3	7.18	0.62	0.56	0.08	0.07	24	19	58
25.....	1.7	5.0	2.9	7.80	0.60	0.37	0.08	0.16	30	18	52
26.....	1.2	4.2	2.3	6.44	0.82	0.40	....	0.06	30	16	54
27.....	1.8	5.1	2.3	7.53	0.84	0.37	0.05	0.15	25	20	55
27.....	1.8	5.0	2.2	7.72	0.82	0.34	0.06	0.07	24	20	56
27.....	1.6	5.1	2.6	7.68	0.46	0.37	0.08	0.03	28	17	55
28.....	1.1	3.6	2.0	6.12	0.47	0.23	0.05	0.05	30	16	54
28.....	1.6	4.4	2.0	6.20	0.47	0.23	....	0.11	25	20	55
28.....	1.4	3.7	1.9	6.05	0.49	0.23	0.04	0.09	27	20	53
31.....	1.3	5.2	3.1*	7.54	1.24	0.60	0.02	0.16	32	14	54
32.....	1.3	8.3	5.7*	11.15	2.38	1.54	0.10	0.10	37	9	54
32a.....	1.2	7.5	5.0*	10.32	1.91	1.28	0.06	0.15	37	8	55
33.....	1.4	4.1	2.1	6.31	0.71	0.38	0.05	0.08	28	18	54
34.....	1.4	3.7	2.3	6.08	0.63	0.37	0.05	0.11	31	19	50
34.....	1.2	3.8	2.0	6.15	0.73	0.31	....	0.06	29	17	54
34.....	1.2	3.8	2.0	6.18	0.56	0.31	....	0.13	29	17	54
35.....	1.3	5.1	4.0	6.44	2.07	1.00	0.08	0.11	38	13	49
35.....	1.9	6.1	3.1	8.52	1.49	0.76	0.05	0.09	28	17	55

35	2.1	7.1	3.5	9.31	1.82	0.96	0.06	0.16	28	16	56	Sept. 18
36	1.2	5.7	2.7	6.86	1.08	0.73	0.05	0.10	28	13	59	July 31
37	0.9	1.9	2.5	4.23	0.80	0.28	.....	.....	47	17	36	Aug. 28
37	1.0	1.9	2.6*	4.60	0.82	0.34	.....	0.04	47	18	35	Oct. 13
37	0.8	1.8	2.5	4.46	0.51	0.31	.....	0.14	49	16	35	Dec. 17
38	1.3	3.8	2.3	6.12	1.52	0.34	0.05	0.08	31	18	51	July 31
38	1.2	3.8	2.2	6.04	0.63	0.34	0.03	0.05	30	17	53	Sept. 18
38	1.1	3.7	2.1	6.12	0.58	0.34	.....	0.12	30	16	54	Dec. 22
39	1.7	6.1	3.3*	8.85	1.41	0.68	0.08	0.06	30	15	55	Aug. 3
40	1.3	5.6	1.9	7.70	0.58	0.34	0.02	0.10	22	15	63	Aug. 7
43	0.8	0.5	4.2	4.12	0.73	0.51	.....	0.08	76	15	9	Aug. 1
45	1.6	9.7	2.9	10.20	1.36	0.28	2.19	0.15	20	11	68	July 30
46	2.0	7.3	3.1	9.57	1.34	0.76	0.13	0.15	25	16	59	June 30
47	2.2	8.0	1.5*	8.92	1.60	0.85	0.32	0.05	13	19	69	July 30
49	0.9	4.4	4.2	6.34	1.34	0.90	.....	0.11	44	10	46	June 30
51	1.1	3.7	3.1	6.03	0.90	0.73	.....	0.11	39	14	47	June 30
52	1.0	5.1	4.3	7.18	1.62	1.04	0.00	0.07	41	10	49	Aug. 7
53	1.2	4.2	2.7	5.87	1.20	0.79	.....	0.15	33	15	52	June 30
53	1.3	4.3	2.6*	5.94	1.35	0.82	0.02	0.08	32	16	52	July 31

* Calculated.

TABLE 4
VARIATION IN COMPOSITION OF WELL WATERS FROM PUTAH CREEK BASIN WITH DEPTH OF WELL AND DEPTH OF PERFORATION*
(Composition expressed in parts per million)

Depth of well, feet	Depth of perforation, feet	Well no.	Cations					Anions					Total solids at 105° C	SiO ₂	Hardness, as CaCO ₃		Date (1931)
			Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Fe ⁺⁺ or Fe ⁺⁺⁺	HCO ₃ ⁻	SO ₄ ⁼⁼	Cl ⁻	NO ₃ ⁻ or NO ₂ ⁻	Al as H ₂ AlO ₃ ⁻			Total	Non-carbonates	
70	35-69	S	38	54	23	0.0	0-0.03	385	31	25	15	2.3	450	368	52	Aug. 6	
80	55-70	45	33	118	66	0.0	0.01-0.02	625	65	10	136	5.6	502	565	42	July 30	
96	80-90	19	38	42	33	0.0	0-0.03	254	47	45	2	2.0	415	266	0	Sept. 18	
105	81-101	46	39	89	70	0.0	0.01-0.02	584	64	37	3	2.7	361	221	13	Aug. 6	
120	100-120	25	34	61	66	0.5-1.0	0.01-0.02	476	29	13	5	6.1	467	382	0	June 30	
137	126-137	27	36	62	53	0.5-1.0	0.02-0.04	459	40	13	3	5.6	462	333	0	July 31	
137	126-137	27	36	60	50	0.0	0.02-0.04	471	39	12	4	2.6	494	341	0	June 30	
137	126-137	27	31	62	59	0.5-1.0	0.04-0.08	463	22	13	5	3.2	488	337	0	July 30	
144	144-164	7	35	40	19	1	0-0.03	291	24	10	2	3.0	318	250	12	Aug. 6	
146-180	146-180	53	25	51	63	0.5-1.0	0.04-0.08	358	57	28	0	5.6	782	274	0	June 30	
175	151-171	53	26	62	60†	0.0	0.04-0.08	362	65	29	1	6.1	447	280	0	July 31	
226	191-220	31	25	63	44	0.5-1.0	0-0.02	470	28	12	1	3.8	436	341	0	Aug. 7	
240	206-240	41	26	65	44	0.5-1.0	0-0.02	470	28	12	1	3.8	436	341	0	Aug. 7	
260	226-260	36	24	69	62	0.0	0.04-0.08	418	43	26	3	4.0	479	240	0	June 30	
268	262-268	28	22	44	45	0.5-1.0	0.04-0.08	373	23	9	3	2.1	377	238	0	July 30	
268	262-268	28	31	54	46	0.5-1.0	0.02-0.03	373	22	9	0	4.1	447	300	0	July 30	
268	262-268	28	29	45	44	0.5-1.0	0.02-0.03	399	23	8	3	3.3	373	255	0	Sept. 18	
369	311-323	34	29	45	62	0.0	0.01-0.02	371	30	13	3	4.1	394	258	0	Sept. 18	
369	311-323	34	25	47	47	0.5-1.0	0.01-0.02	375	35	11	0	2.1	390	254	0	Sept. 18	
369	311-323	34	24	46	45	0.5-1.0	0-0.26	377	27	11	3	4.9	384	250	0	Dec. 17	
369	312-324	38	26	46	53	0.5-1.0	0.04-0.08	377	73	12	3	2.9	399	34	0	July 31	
420	312-324	38	24	46	50	0.5-1.0	0.02-0.04	368	30	12	2	1.8	374	248	0	Sept. 18	
420	312-324	38	23	44	49	0.5-1.0	0.04-0.08	373	28	12	0	4.7	372	249	0	Dec. 17	
420	400-420	26	25	51	53	0.0	0.04-0.08	393	40	14	0	2.4	403	272	0	Aug. 6	
552	430-450	37	18	23	57	0.5-1.0	0.00-0.02	258	38	10	0	1.7	288	140	0	Aug. 28	
552	430-450	37	19	23	68†	0.5-1.0	0.01-0.02	274	25	12	0	5.2	321	142	0	Oct. 13	
552	430-450	37	15	22	57	0.5-1.0	0.05-1.00	172	23	11	0	5.2	293	130	0	Dec. 17	
552	430-450	23	21	24	47	0.01-0.02	0.01-0.02	254	25	12	0	1.4	300	151	0	Sept. 25	
1,030	{ 546-557 } { 553-568 } { 569-573 } { 582-592 } { 598-610 } { 1,004-1,020 }	43	16	6	97	0.0	0.0	251	35	19	0	3.0	349	65	0	Aug. 1	

* Phosphorus (as PO₄--) was less than 1.0 p.p.m. for all samples. Carbonate (as CO₃--) was less than 0.5 p.p.m. for all samples except in the case of well no. 43, which had 6 p.p.m.

† Calculated.

45, showed 136 p.p.m. of N calculated as NO_3^- , or nitrate nitrogen. A sample from this well was tested by Dr. C. S. Mudge^o and the *Bacillus coli* group of organisms was not isolated.

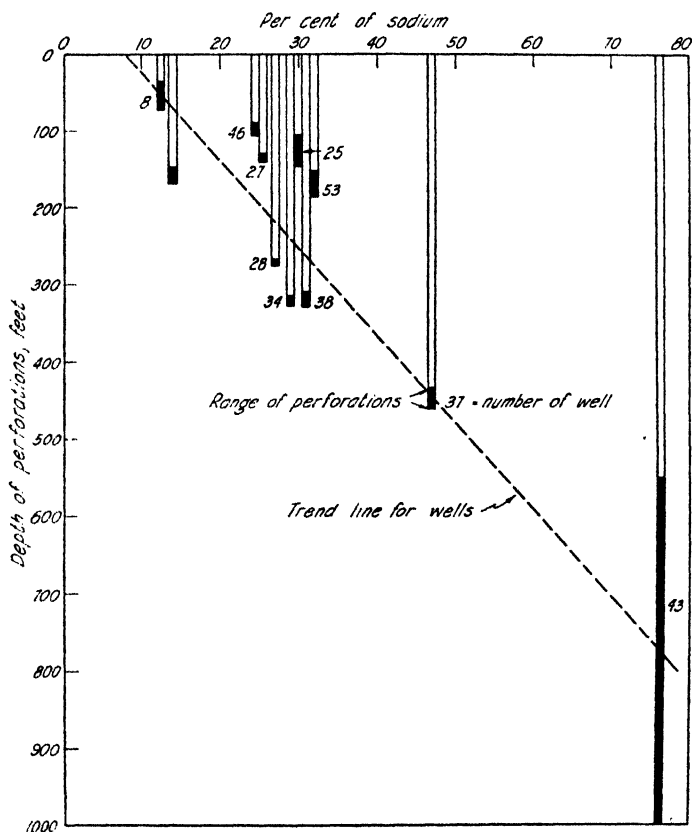


Fig. 2.—Relation between depth of water-bearing formation and the amount of sodium of the well waters. "Per cent of sodium" refers to the ratio between the number of milliequivalents per liter of sodium ions and the total number of equivalents of positive ions in the solution expressed as percentage. The solid bars indicate the range in depths of perforations.

Table 4 shows the results of tabulating the wells of this area with respect to depth and chemical constituents. The range of depth is from 35 feet to 1,030 feet, and with the exception of well no. 43, involves only wells perforated at one stratum. It is clearly evident that the ratio of calcium and magnesium to sodium is lower in the water from deep wells

^o Associate Professor of Dairy Industry and Dairy Bacteriologist in the Experiment Station.

TABLE 5
BORON CONTENT OF WELL WATERS IN PUTAH CREEK BASIN

Well no.	Boron p.p.m.	Well depth, feet	Perforation depth, feet	Date (1932)	Well no.	Boron, p.p.m.	Well depth, feet	Perforation depth, feet	Date (1932)
1.....	0.83			Sept. 18	30	0.74			Sept. 24
2.....	0.07			Sept. 18	33	0.37	330		Sept. 15
3.....	0.17			Sept. 18	34	0.52	369	311-323	Sept. 14
4.....	0.41			Sept. 18	35	1.04	322	Several strata	Sept. 15
5.....	0.09			Sept. 18	37	0.28	552	430-450	Sept. 18
6.....	0.09			Sept. 18	38	0.34		312-324	Sept. 16
7.....	0.16			Sept. 18	39	0.57			Sept. 16
8.....	0.09	70	35-49	Sept. 18	40	0.22	226	212-220	Sept. 18
9.....	0.46	170		Sept. 18	41	0.69	125		Sept. 28
10.....	0.20			Sept. 18	42	0.34	125		Sept. 28
11.....	0.14			Sept. 18				546-557	
12.....	0.04			Sept. 18				653-696	
13.....	0.46			Sept. 18				767-776	
14.....	0.56			Sept. 24	43		1.030	803-813	Sept. 16
15.....	0.24			Sept. 18				898-910	
16.....	0.04			Sept. 16				1,004-1,020	
17.....	0.00			Sept. 16	45		80		Sept. 15
18.....	0.15	96	80-90	Sept. 16	46	1.12	105	81-101	Sept. 15
19.....	0.32	138		Sept. 24	48	0.49			Sept. 24
20.....	0.36			Sept. 24	49	0.50			Sept. 15
21.....	0.07			Sept. 16	50	0.86			Sept. 15
22.....	0.11			Sept. 18	51	2.02			Sept. 15
23.....	0.04	100	486-511	Sept. 18	52	0.96	240	204-240	Sept. 15
24.....	0.30	120	70-77	Sept. 16	53	0.94			Sept. 18
25.....	0.45	420	100-120	Sept. 18		0.30		146-180	Sept. 15
26.....	0.65	137	400-420	Sept. 18					
27.....	0.44	268	126-137	Sept. 15					
28.....	0.49	123	262-268	Sept. 15					
29.....			107-120	Sept. 15					

than that from shallow wells. This is clearly shown in figure 2, which was constructed from data of analyses of waters from a few wells of various depths located near the channel of Putah Creek. The average depth of water-bearing strata varied from 50 to 770 feet below the ground surface. Percentage of sodium refers to the ratio between the number of milliequivalents per liter of sodium ions and the total number of equivalents of positive ions in the solution expressed as percentage. The graph indicates that the sodium percentage increases with increases in depth of water-bearing strata, the variation being from 12 per cent for the shallow aquifers to 76 per cent for the deepest water-bearing stratum.

The boron content of the well waters is given in table 5. From the data obtained it appears that the area of highest boron content is east of Davis several miles. The wells having the lowest boron content are in the vicinity of Dixon and Winters. It was not possible to correlate depth of perforation with boron content.

CONCLUSIONS

Within the period of time covered by these studies, water from wells perforated at one stratum only, but of various depths, is remarkably constant with respect to chemical composition. Wells perforated at more than one strata show a variable salt content.

In general, the ground waters of Putah Creek basin are of good quality for irrigation. The total salt content is relatively low as is the sodium percentage. Some well waters, however, contain sufficient boron to cause injury to many crop plants.

The well waters of this area are characterized by a relatively high bicarbonate content. The sodium percentage increases with depth of water-bearing formation. The boron content varied between 0 and 2.02 parts per million.

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THE EFFECTS OF PHOSPHORUS DEFICIENCY ON CITRUS^{1,2}

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NEW D

INTRODUCTION

INFORMATION CONCERNING the effects of mineral deficiencies and excesses on plants has proved of great value in the diagnosis of nutritional disorders in the field and has also provided many clues as to the function and interrelation of elements in plant metabolism and nutrition. In the case of citrus, knowledge of this subject, though extensive, is far from complete. Certain deficiencies, for example, have never been seen or produced on bearing trees; nor is it known, in many instances, which of the effects of a deficiency are primary and which secondary. Investigations concerned with various phases of citrus nutrition have led to the realization that a more thorough understanding of this subject is indispensable—is, in fact, a necessary cornerstone for further effective work. There are indications, too, that certain obscure physiological disorders affecting fruit production and fruit quality may be related to nutrition. Hence considerable experimental work has been carried out and is under way to extend our knowledge of the incipient and acute effects of deficiencies and excesses of mineral elements on the various species of citrus.

In connection with a soil-fertilizer experiment with young navel-orange trees in large containers (55-gallon oil drums), acute phosphorus deficiency developed in one of the soils used. Since, to the knowledge of the authors, the effects of a lack of this element on bearing oranges have never been described, an account of the onset and progress of this disorder is set forth herein.

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² Paper no. 436, University of California Citrus Experiment Station, California.

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EXPERIMENTAL PROCEDURE

The fertilizer experiment referred to was begun in January, 1934, to determine whether large variations in the nitrogen, phosphorus, and potassium supply of soils would produce measurable effects on fruit quality.

Differential fertilizer treatments, as shown in table 1, were given duplicate cultures of each of two soils—one a calcareous Hanford fine sandy loam of low phosphate availability, from Santa Ana, California;

TABLE 1
DIFFERENTIAL FERTILIZER TREATMENTS GIVEN SOILS IN OIL DRUMS

Hanford fine sandy loam cultures	Sierra loam cultures	Fertilizer treatment	Amounts applied					
			Nitrogen as N		Phosphorus as P ₂ O ₅		Potassium as K ₂ O	
			Per oil drum	Rate per acre*	Per oil drum	Rate per acre	Per oil drum	Rate per acre
			grams	lbs.	grams	lbs.	grams	lbs.
1 and 2	13 and 14	None.....	0 00	0	0 0	0	0 0	0
3 and 4	15 and 16	N (calcium nitrate).....	13 75	482	0 0	0	0 0	0
5 and 6	17 and 18	NP (calcium nitrate and dicalcium phosphate).....	13 75	482	136 5	4.784	0 0	0
7 and 8	19 and 20	NK (calcium nitrate and potassium sulfate).....	13 75	482	0 0	0	33.8	1,185
9 and 10	21 and 22	NPK (calcium nitrate, dicalcium phosphate, and potassium sul- fate).....	13 75	482	136.5	4.784	33.8	1,185
11 and 12	23 and 24	NPK (calcium nitrate, dicalcium phosphate, and potassium sul- fate).....	13 75	482	273.0	9.568	33.8	1,185

* Rate per acre on area basis; the soil-surface area in the oil drums was 2.74 sq. ft.

the other a virgin Sierra loam containing ample available phosphate, from the University of California Citrus Experiment Station at Riverside. Enough of each soil was obtained to fill twelve 55-gallon containers, each soil being thoroughly mixed before filling the containers. The fertilizers used were calcium nitrate, dicalcium phosphate, and potassium sulfate. The phosphate and potassium sulfate were subsequently mixed about the soil of each of the cultures receiving these treatments. Nitrate was applied in solution to the top of the soil. At frequent intervals in the course of this experiment, subsequent applications of fertilizer were given to those cultures receiving nitrogen, but no further nitrogen or potassium fertilizer was added, save a surface application of dicalcium phosphate to the soil in culture 4 later in the experiment. This tree had become phosphorus-deficient; this was for the pur-

pose of testing the diagnosis. The cultures were watered with distilled water. The experiment was set up in a screened enclosure out of doors.

Oats were grown in the containers during the first year (1934) in order to provide preliminary information on responses to the fertilizer.

On March 4, 1935, one-year-old budded navel-orange trees, especially selected for uniformity, were planted in the containers. The appearance of the trees in the Hanford fine sandy loam, three months after transplanting, is shown in figure 1. Tomatoes were also grown in the containers at this time to determine whether the phosphate which had been

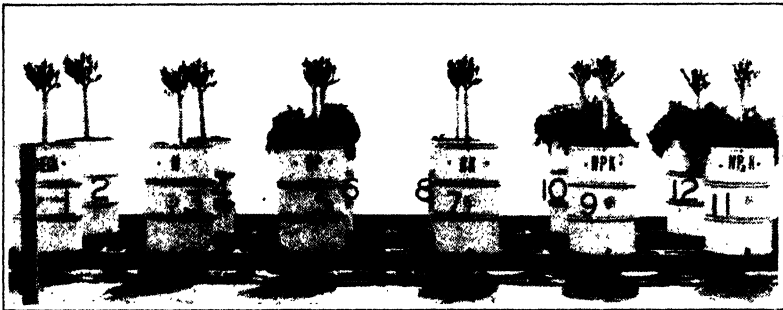


Fig. 1.—Young navel-orange trees three months after transplanting in differentially fertilized cultures. Two replicates. Fertilizer treatment was as follows: cultures 1 and 2, no treatment; cultures 3 and 4, calcium nitrate; cultures 5 and 6, calcium nitrate and dicalcium phosphate; cultures 7 and 8, calcium nitrate and potassium sulfate; cultures 9 and 10, calcium nitrate, dicalcium phosphate, and potassium sulfate; cultures 11 and 12, same as that for 9 and 10 save that twice as much dicalcium phosphate was used in these cultures. Note failure of interplanted tomatoes to grow in cultures which received no phosphate treatment.

applied seventeen months previously was still effective. Figure 1 shows that the added phosphate was still available and also demonstrates the extreme unavailability of the native phosphate of this soil for this plant; practically no growth was made in those cultures which received no phosphate. Subsequent trials with interplanted tomatoes gave similar results.

DEVELOPMENT AND DIAGNOSIS OF PHOSPHORUS DEFICIENCY

During the first three years (March, 1935, to March, 1938), no significant differences in growth of the citrus trees resulted from the differential fertilizer treatments in the Hanford soil, save for nitrogen deficiency in those cultures not receiving nitrate.* The green fruits which

* This was true in the case of the Sierra loam soil as well. Subsequently the trees in the Sierra loam soil developed an acute sulfur deficiency, the effects of which are described in the succeeding paper (6).

set in 1936 were picked; fruits which set in 1937, 1938, 1939, and 1940 were allowed to remain on the trees and ripen.

After the spring bloom in 1938, the four trees growing in the Hanford soil and receiving the nitrogen or nitrogen and potassium treatments (cultures 3, 4, 7, and 8) began to shed an abnormal number of leaves, as compared with the trees receiving phosphate. It was further noted that many of the falling leaves had burned areas and were of a dull-green color with a bronze cast. The low availability of the phosphate of

TABLE 2
PHOSPHATE IN HANFORD SOIL AFTER FOUR YEARS' CROPPING,
COMPARED WITH PHOSPHATE OF ORIGINAL SOIL

Soil sample tested	Fertilizer treatment*	Phosphate (PO_4^{3-}) in dry soil	
		Water-soluble†	Acid-soluble‡
Original soil	None	p. p. m. 0.37	p. p. m. 131.4
Culture:			
1.....	None	0.00	.....
2.....	None	0.00	.....
3.....	N	0.00	121.0
4.....	N	0.00	121.0
5.....	NP	24.50	.....
6.....	NP	24.50	.....
7.....	NK	0.00	.....
8.....	NK	0.00	.....
9.....	NPK	25.70	.....
10.....	NPK	24.50	.....
11.....	NPK	24.50	.....
12.....	NPK	22.30	.....

* For explanation of fertilizer treatment see table 1 (p. 162).

† Determination on 100 milliliters of a 1:5 water extract by the blue colorimetric method.

‡ Determination by the Truog (17) method; these tests were run only on the original soil and on cultures 3 and 4.

this soil immediately suggested phosphorus deficiency as the possible cause. Analyses of the woody tissue of one of these trees (no. 3) for inorganic phosphate (5)* showed only 23 p. p. m. PO_4^{3-} , on a green-weight basis, whereas similar tissue from a phosphate-treated tree (no. 5) contained 250 p. p. m. PO_4^{3-} . Determination of total phosphorus in burned and abscised leaves from tree no. 3 showed 0.07 per cent as against 0.13 per cent in comparable leaves taken from tree no. 15 growing in the Sierra loam soil, which received the same fertilizer treatment (calcium nitrate) but had none of the phosphorus-deficiency symptoms.

Soil samples taken from all the Hanford soil cultures on September 29, 1938, together with a sample of the original soil, were tested

* Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

for water-soluble phosphate. Determinations of acid-soluble phosphate, made by the Truog (17) method, were also run on the original soil and on samples from cultures 3 and 4. The results of these tests are presented in table 2. Although the original soil contained a measurable amount of water-soluble phosphate, no trace was found in those cultures which did not receive phosphate treatment. On the other hand, there was almost as much acid-soluble phosphate present in cultures 3 and 4 as in the original uncropped soil, which indicates that the citrus trees had not materially reduced the reserve phosphate supply of this soil.

TABLE 3
COMPARATIVE CROSS-SECTIONAL AREAS OF TRUNKS OF NAVEL-ORANGE TREES
GROWN IN DIFFERENTIALLY FERTILIZED SOILS, 1937-1940

Trees	Fertilizer treatment*	Average cross-sectional area of tree trunks†				
		Dec. 28, 1937	Sept. 24, 1938	Oct. 14, 1939	May 17, 1940	Net increase 1937-1940
		<i>sq. cm</i>	<i>sq. cm</i>	<i>sq. cm</i>	<i>sq. cm</i>	<i>sq. cm</i>
1 and 2	None	6.9	8.1	8.5	8.7	1.8
3 and 4	N	9.6	11.9	13.7	14.2	4.6
5 and 6	NP	9.6	13.4	16.2	16.1	6.5
7 and 8	NK	9.7	13.6	15.6	15.8	6.1
9 and 10	NPK	9.2	13.2	16.7	17.7	8.5
11 and 12	NPK	9.6	14.1	17.4	18.6	9.0

* For explanation of fertilizer treatment see table 1 (p. 162).

† Figures are averages of measurements at three permanently marked points (see fig. 2) on trunks of two trees in duplicate cultures.

Further evidence that the malnutrition noted was phosphorus deficiency was provided by the fact that phosphate applications to the surface of the soil of culture 4 in the summer of 1939 brought about definite tree recovery.

EFFECT OF PHOSPHORUS DEFICIENCY ON GROWTH AND APPEARANCE OF TREES AND ON FRUIT

The average cross-sectional areas of the trunks of the differentially fertilized trees in duplicate cultures, at various periods from December, 1937, to May, 1940, are shown in table 3. The measurements in 1937 were made before any symptoms of malnutrition had become evident. All save the nitrogen-deficient trees had made a very uniform growth up to this time. The subsequent retarded growth of the phosphorus-deficient trees is definitely shown by these data. This is more strikingly brought out by pictures of trees 3 and 5, taken in the spring of 1939 (plate 2, *A* and *B*). Color pictures of trees 3 and 5, taken a year later (plate 1), show the continued decline of the phosphorus-deficient tree.

Weak and limited new growth, premature abscission of older leaves, dieback of weakened twigs, together with a dull-green to bronze color of the foliage, were the more common features of this disorder. The leaves were small, somewhat thickened, and stood more upright in relation to the stem than normal leaves. No unusual twig, trunk, or root symptoms, such as splitting or gumming, have been observed to date.

Perhaps the best diagnostic symptom, though by no means the most conspicuous, is a burn which occurs on the older leaves. This is most pronounced in the spring after the emergence of the blossoms and new foliage.

From studies of phosphorus-deficient lemon plants grown from cuttings in the greenhouse in solution cultures, as well as from the aforementioned observations on bearing trees, it appears that the burn and premature abscission of older leaves takes place most prominently during periods when active terminal growth is being made. A seventeen-month-old, phosphorus-deficient lemon plant and a healthy lemon plant of the same age, both grown in the greenhouse, are shown in figure 2. Note that the older leaves of the phosphorus-deficient plant have been shed and, also, that leaf size is somewhat reduced. At the time these pictures were taken, new terminal growth was continuing to appear on the plant lacking phosphorus, and the older leaves along the lower stem were, concurrently, being shed. Many, though by no means all, of the falling leaves showed burn; all had a bronzed, lusterless appearance. The effects of phosphorus deficiency on lemon plants grown in the greenhouse agree with those described by Haas (10) for similarly grown citrus plants.

Apparently, there is a translocation of phosphorus from the older to the developing leaves as the supply of phosphate becomes deficient. Tests for inorganic phosphate at various points along the stem of the phosphorus-deficient lemon plants grown in the greenhouse showed much higher amounts at the growing point than toward the base. The total phosphorus content of old leaves shed at a point 36 inches up the stem from the base of the plant was 0.062 per cent; that of leaves 72 inches up the stem was 0.075 per cent; while that of green terminal leaves, 96 inches from the base, was 0.15 per cent. Corresponding leaves from healthy plants of similar age showed a total phosphorus content ranging from 0.15 to 0.25 per cent.

The burn noted on the leaves of the phosphorus-deficient trees often started as a discoloration (plate 1, *E*), giving them somewhat of a water-soaked appearance. Shortly thereafter, this area died completely (plate 1, *F* and *G*). At this stage, the injury resembled certain types of salt burn; in fact, so far as appearance is concerned, leaves burned at the

tip through phosphorus deficiency are indistinguishable from those injured by chloride. But, whereas the burned phosphorus-deficient leaves occur in greatest abundance in the spring, salt injury is more commonly seen in the fall and winter.



Fig. 2.—Seventeen-month-old lemon plants grown (A) in phosphate-deficient solution and (B) in complete nutrient solution. Note premature abscission of old leaves on the phosphorus-deficient plant. Both plants were grown in complete nutrient solution for thirteen months, after which the plant on the left (A) was deprived of phosphate.

Although the four phosphorus-deficient navel-orange trees (nos. 3, 4, 7, and 8) blossomed profusely in the spring of 1938, no fruit was produced, in contrast to a good set of fruit on the six trees receiving phosphate. Very weak, sparse bloom has characterized these trees in subsequent years, and the spring vegetative cycle has been limited (plate 1, D and C). The failure of these trees to bear fruit during the three years after they became phosphorus-deficient is clearly shown in table 4. A record of the fruit produced on all the differentially fertilized trees of this experiment, from 1935 to 1941, is set forth in this table.

Various quality studies were made on the fruits borne by the trees in all cultures in the year 1937-38, just preceding the onset of the phosphorus deficiency in cultures 3, 4, 7, and 8. The fruits were picked on

TABLE 4
NUMBER OF FRUITS BORNE BY NAVEL-ORANGE TREES GROWN IN DIFFERENTIALLY
FERTILIZED HANFORD SOIL CULTURES, 1935-1941

Trees	Fertilizer treatment*	Total number of fruits on trees in replicate cultures					
		1935-36	1936-37†	1937-38	1938-39	1939-40	1940-41‡
1 and 2.....	None	0	0	0	0	0	0
3 and 4.....	N	0	9	10	0	0	0
5 and 6.....	NP	0	1	10	20	20	109
7 and 8.....	NK	0	6	13	0	2	0
9 and 10.....	NPK	0	9	10	37	37	46§
11 and 12¶	NPK	0	3	4	5	28	50

* For explanation of fertilizer treatment see table 1 (p. 162).

† Fruits picked green June 22, 1936.

‡ Green fruits on trees August 19, 1940.

§ Fruits on tree 10 only; tree 9 was harvested earlier.

¶ These two trees showed periodic symptoms of malnutrition, owing to the heavy phosphate applications given at the beginning of the experiment, and fruit production on these trees was subnormal.

February 4, 1938, and while at this time no symptoms of malnutrition were evident in the non-phosphate-treated trees, it was just after the spring blossom that the abnormally heavy leaf fall referred to took

TABLE 5
CHARACTERISTICS OF MATURE NAVEL ORANGES PRODUCED ON TREES GROWN IN
DIFFERENTIALLY FERTILIZED CULTURES, 1937-38

Trees	Fertilizer treatment*	Total fruits produced and tested	Color of rind	Average rind thickness, percentage of total diameter	Average percentage of juice	Average total solids, degrees Brix at 17.5° C	Average anhydrous citric acid in juice	Average total phosphorus in juice
		number		per cent	per cent	° Brix	per cent	per cent
1 and 2	None	0						
3 and 4	N	10	Deep orange	9.7	36.7	13.2	1.14	0.029
5 and 6	NP	10	Yellow orange	8.1	40.5	13.5	0.89	0.064
7 and 8	NK	13	Deep orange	8.2	37.8	13.2	1.05	0.036
9 and 10	NPK	10	Yellow orange	7.6	42.0	13.3	0.77	0.072
11 and 12	NPK	4	Yellow orange	7.0	39.8	13.1	0.92	0.078

* For explanation of fertilizer treatment see table 1 (p. 162).

place. Since these trees must have been in the incipient stage of phosphorus deficiency at this time, the character of the fruit which matured is perhaps suggestive. The more pertinent data are reported in table 5 and show that fruits borne by the trees receiving no phosphate were characterized by a deeper orange color, thicker rind, less juice, higher

acid, and lower phosphorus content than the fruits from the phosphate-treated trees. The potassium treatment also apparently reduced rind thickness somewhat.

Only two fruits have since been produced on the phosphorus-deficient trees (table 4). Like the earlier ones, these fruits were deep orange in color. They had thick, coarse rinds, were decidedly lacking in juice, and were puffy. The fruits from the phosphate-treated trees during this same year, examined on the same date, had much thinner and smoother rinds, were very juicy, and showed no puffiness. More data will be needed to characterize definitely the effects of phosphorus deficiency on citrus fruit, but the preceding information is suggestive and fits in with existing evidence as to the influence of phosphorus on fruit quality (1, 2).

MINERAL COMPOSITION OF PHOSPHORUS-DEFICIENT ORANGE TREES

In order to characterize further the effects of phosphorus deficiency, inorganic analyses were made of various parts of phosphorus-deficient tree no. 8 and of healthy tree no. 9. These two trees were removed from the cultures in July, 1940. Samples of leaves, pencil-sized twigs, trunks, pencil-sized roots, and fine roots were washed in tap water and rinsed in distilled water. The bark was separated from the twigs, trunk parts, and pencil-sized roots; the interior woody parts were ground in a pencil sharpener while still green; and the bark, leaves, and fine roots, when air-dry, were ground in a Wiley mill. The samples were dried at 105° C, and analyses were made according to accepted procedures. The results are shown in table 6.

All parts of the phosphorus-deficient tree were low in phosphorus. The greatest contrast in the total phosphorus of the deficient and healthy plants was found in the bark and wood of the twigs, trunk, and coarse roots; the least difference was found in the young leaves. The older leaves were lower in phosphorus than the young leaves. These results indicate that the bark or woody tissue is more expressive as regards phosphorus status and more critical for diagnostic purposes than the leaves.

With the exception of the trunk wood, the nitrogen content of all parts of the phosphorus-deficient tree was higher than that of corresponding parts of the healthy plant. The differences in nitrogen content were most pronounced in the old leaves and the twig bark; and while the differences in the young leaves, interior root wood, and fine roots are small, they are probably significant. This is in harmony with the findings of many other investigators, who have shown that phosphorus-deficient plants are high in nitrogen and that nitrogen-deficient plants are high in phosphorus.

The potassium content of the young and old leaves and of the fine roots taken from the phosphorus-deficient tree was also higher than that of corresponding parts of the healthy tree; but in the other plant parts, the condition was just the reverse. The calcium and ash contents of the

TABLE 6
COMPARATIVE INORGANIC COMPOSITION OF PARTS OF PHOSPHORUS-DEFICIENT AND
HEALTHY NAVEL-ORANGE TREES

Part of tree and condition	Constituents of dry matter, at 105° C								
	Ash	Ca	Mg	K	Na	Cl	N	P	S
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Young leaves:									
Phosphorus-deficient.	12.55	2.84	0.18	2.56	0.08	0.19	3.46	0.14	0.26
Healthy.....	14.23	4.34	.12	1.55	.02	.39	3.38	.18	.23
Old leaves:									
Phosphorus-deficient.	15.63	4.14	.18	2.50	.06	.21	5.00	.05	.23
Healthy.....	22.80	8.17	.09	0.80	.04	.35	1.70	.11	.26
Twig bark:									
Phosphorus-deficient	12.76	4.23	.08	0.43	.08	.09	3.03	Trace	.11
Healthy.....	15.47	5.22	.12	0.62	.05	.14	1.65	.28	.27
Twig wood:									
Phosphorus-deficient.	4.89	1.73	.05	0.17	.05	.11	0.85	Trace	.09
Healthy.....	4.12	1.26	.08	0.24	.04	.14	0.72	.22	.12
Trunk bark:									
Phosphorus-deficient.	12.41	3.20	.44	0.51	.06	.09	1.97	Trace	.63
Healthy.....	13.15	4.40	.35	0.66	.05	.11	1.64	.24	.18
Trunk wood:									
Phosphorus-deficient.	6.26	1.13	.06	0.15	.05	.14	0.46	Trace	.22
Healthy.....	2.49	0.69	.08	0.21	.03	.14	0.60	.16	.11
Root bark:									
Phosphorus-deficient	9.22	2.79	.17	0.52	.08	.32	2.66	.01	.11
Healthy.....	11.00	3.26	.18	0.75	.02	.40	2.15	.24	.20
Root wood:									
Phosphorus-deficient	2.37	0.77	.07	0.06	.05	.11	0.70	.01	.05
Healthy.....	2.64	0.73	.09	0.18	.05	.12	0.66	.16	.08
Fine roots:									
Phosphorus-deficient	18.40	4.32	.22	0.75	.02	.35	2.03	.12	.12
Healthy.....	28.23	4.46	0.22	0.59	0.04	0.32	1.95	0.25	0.14

young and old leaves and of the twig, trunk, and root bark, as well as that of the fine roots, of the phosphorus-deficient tree were definitely lower than that of corresponding parts of the healthy tree; but that of twig and trunk wood was somewhat higher. There was no significant difference in the calcium or ash of the root wood. The differences in magnesium content of parts of the two trees were small; the greatest differ-

ences were found in leaves and in trunk bark, the phosphorus-deficient parts showing the higher content. In most cases, the sodium, chlorine, and sulfur contents were not much affected.

The burn which occurs on many of the older leaves and which, in the case of some leaves, is indistinguishable from chloride injury, is clearly not the result of chloride accumulation. The high nitrogen and potassium content of these old leaves, coupled with the observations of Eckerson (8), that phosphorus-starved plants store nitrate, suggests that the burn may be a result of excessive potassium nitrate accumulation. This possibility is being explored. Breakdown and disorganization of the cell protoplasm were noted by Reed (16) and Eckerson (8) in their studies of the effects of acute phosphorus deficiency.

DEVELOPMENT OF MANGANESE-DEFICIENCY SYMPTOMS ON PHOSPHORUS-DEFICIENT TREES

A further observation of considerable interest was the appearance of leaf symptoms of manganese deficiency on the summer-cycle growth of all the phosphorus-deficient trees in 1939 and again in 1940. When sprayed with manganese chloride, such leaves became green. A twig from a phosphorus-deficient tree, showing the typical manganese-deficiency leaf patterns (7) and the prompt recovery induced on a single leaf by painting with a dilute solution of manganese chloride, is presented in plate 2, C'. The trees receiving phosphate showed no such symptoms.

Lyons (13, 14) has found that respiration and the production of carbon dioxide in green plants is pronouncedly increased by the use of phosphates, and Eckerson (8) has shown that reductase activity, as evidenced by nitrate accumulation, is decreased when phosphate is lacking. That phosphate is intimately linked with the vital activities of cells is indicated by the work of these and other investigators. It seems logical to infer that the appearance of manganese deficiency in the phosphorus-deficient trees of this experiment was owing to the decreased respiration of plant roots, which limited the production of carbon dioxide accordingly and consequently diminished solvent action on the sparingly soluble manganese compounds of this calcareous soil. That the manganese deficiency noted is a result of decreased solvent action of plant roots rather than a result of failure to utilize manganese after it has gained entrance into the plant is indicated (1) by the fact that manganese applications to the leaf brought about recovery; and (2) by the observations that the spring growth, in contrast to that of the summer and fall cycles, in 1939 and again in 1940, showed no manganese-deficiency symptoms. The trees were evidently able to absorb and store enough manga-

nese during the winter period, when vegetative growth is at a minimum, to suffice for the spring cycle.

DISCUSSION

While the phosphorus-deficient citrus trees of this experiment showed none of the anthocyanin pigmentation which is common on the stems and leaves of many plants lacking phosphorus (3, 8, 9, 11, 12, 15, 18), many characters similar to the effects of a deficiency of this element on other plants were apparent. Of these, greatly reduced growth rate, small leaves, lack of branching, continued terminal growth (weak and slow, however) at the expense of the older leaves, and bronze or dull-green color of old leaves were the most evident.

On tobacco, Karraker and Bortner (12) and McMurtrey (15) describe a necrotic spotting of the older leaves caused by phosphorus deficiency, though McMurtrey states that this character does not always develop. With citrus, the burn on older leaves occurs chiefly during periods when terminal growth is being made. Despite the somewhat irregular advent of this injury, it is perhaps the most diagnostic symptom; for sparse growth, open trees, and dull-green leaves may result in citrus from other causes also. Though the burn on some leaves resembles chloride injury, the latter occurs more commonly in the fall and winter, while the necrosis due to the lack of phosphorus is more prominent in the spring, after the emergence of the bloom and new-cycle growth.

Leaf analysis provides a fairly reliable means of distinguishing between the two injuries, since chloride-injured leaves show accumulations of chloride, whereas leaves burned as a result of phosphorus deficiency show no chloride accumulation and are distinctly subnormal in phosphorus content. Analyses of various parts of trees lacking phosphorus have also shown that the bark and woody tissue of pencil-sized twigs are exceedingly low in both total and inorganic phosphorus. These tests, together with the other symptoms described, would appear to be sufficient for diagnostic purposes when the deficiency is acute. As in other deficiencies, however, confirmatory tests, such as soil and plant treatments with phosphorus, should be undertaken as a final check.

The development of acute phosphorus deficiency in citrus grown in soil cultures has raised the question as to the possible phosphate needs of citrus grown under field conditions on comparable soils. A recent survey has been made of commercial citrus groves located on soils similar to the Hanford sandy loam used in this experiment. None of the trees in these groves showed any of the symptoms of phosphorus deficiency herein described, and tests for inorganic phosphate in the woody tissue of a number of the trees showed definitely higher amounts than were

found in the phosphorus-deficient trees of the experimental cultures. The acute deficiency which developed under the conditions of this experiment is probably accounted for by the restricted volume of soil available for root development. Under field conditions, with a much larger body of soil available for root growth, it is unlikely that acute phosphorus deficiency would develop. Moreover, the soils of the majority of commercial orchards in California (4) have been found to contain substantial accumulations of phosphate, owing to the past use of manures and mixed fertilizers. The continued use of manures or bulky organic materials will no doubt supply adequate phosphate for citrus needs, even though the phosphate of the original soil may be somewhat low.

SUMMARY

In connection with a fertilizer experiment on a calcareous Hanford fine sandy loam with young navel-orange trees in 55-gallon containers, an acute phosphorus deficiency developed in those trees receiving nitrogen or nitrogen and potassium but no phosphate.

The onset of this disorder was sudden. An abnormal shedding of leaves, which occurred just after the spring bloom in 1938, three years after planting, was the first indication of malnutrition. Some of the leaves showed burned areas, and many had a dull-green, bronzed, lusterless appearance. Little new growth was made subsequently, and the leaves were somewhat undersized, though not conspicuously so. Spring blossoms in the two succeeding years (1939 and 1940) were meager, and fruit failed to set, save for one fruit each on two trees during the year 1939. These two fruits were small in size, some puffiness was evident, and the juice content was low. With the exception of some dieback, no abnormal twig, trunk, or root symptoms developed. The inorganic and total phosphorus contents of all parts of the tree were subnormal; phosphorus in the bark and woody tissue was especially low. Fruit which matured on the phosphorus-deficient trees just prior to the development of leaf symptoms had a deeper orange color, thicker rind, and less juice than the fruit on the phosphate-treated trees.

A secondary manganese deficiency developed in the phosphorus-deficient trees. This was thought to be the result of the decreased solvent power of plant roots for the sparingly soluble manganese compounds of this soil, occasioned by diminished root respiration.

A survey of the trees of commercial citrus groves located on soils comparable to that used in this experiment showed no symptoms of phosphorus deficiency. Probably the deficiency which occurred in the experimental cultures resulted in part from the restricted root development owing to the limited quantity of soil available for root expansion.

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PLATES

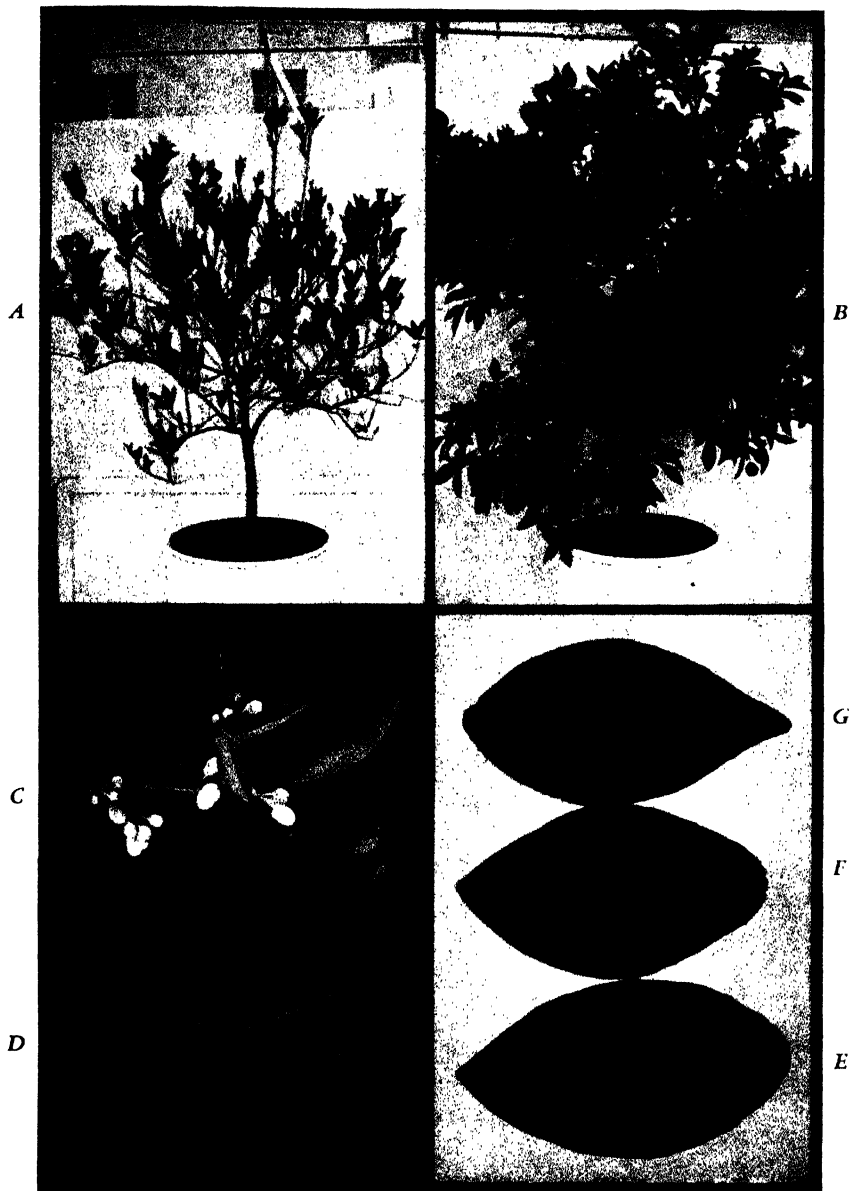


Plate 1.—Phosphorus deficiency of navel-orange tree, shoots, and leaves: *A*, five-year-old phosphorus-deficient tree; *B*, healthy tree, same age; *C*, healthy shoot; *D*, phosphorus-deficient shoot showing small, bronzed, old leaves, lack of bloom, and weak new-cycle growth; *E-G*, phosphorus-deficient leaves, dull green to bronze in color, showing various types of burn on old leaves.

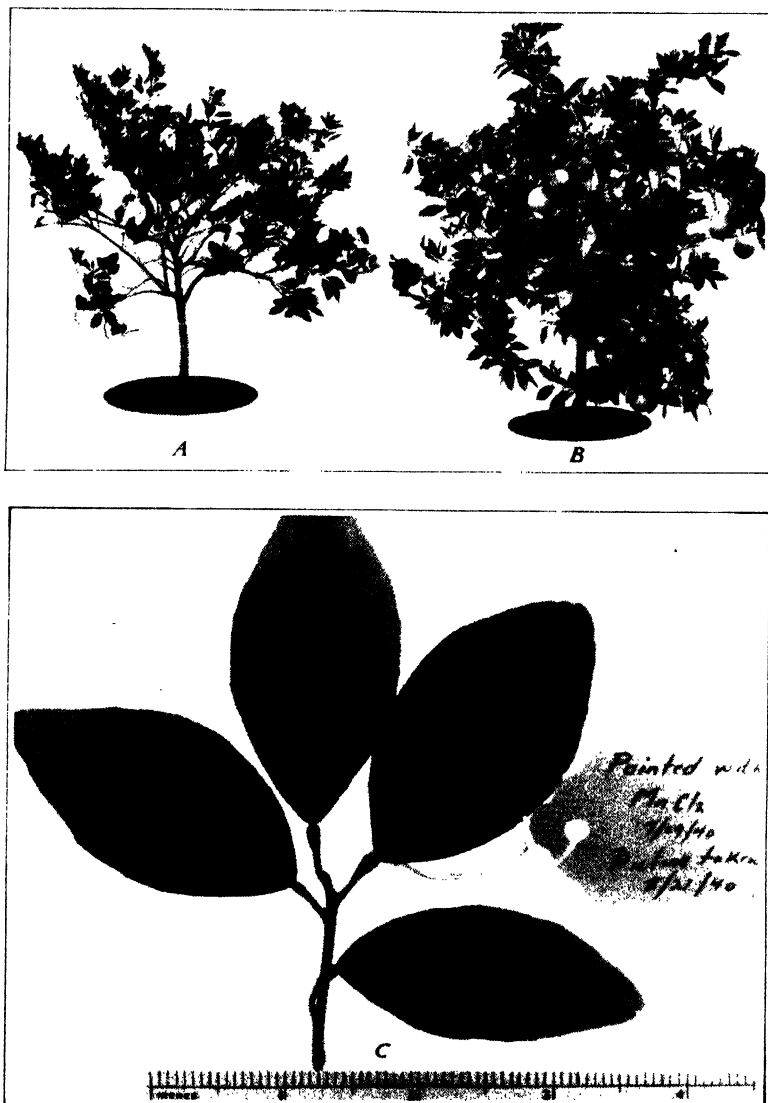


Plate 2.—*A*, Four year-old phosphorus-deficient navel-orange tree (no. 3), showing reduced growth, sparse foliage, dead wood, and lack of fruit. *B*, Healthy tree of like age (no. 5). Both photographed February, 1939. *C*, Manganese-deficient navel-orange leaves which developed on the summer-cycle growth of a phosphorus-deficient tree. The tagged leaf became green less than a month after being painted with a solution of manganese chloride containing 5 milligrams of manganese per milliliter.

THE EFFECTS OF SULFUR DEFICIENCY ON CITRUS

H. D. CHAPMAN AND S. M. BROWN

THE EFFECTS OF SULFUR DEFICIENCY ON CITRUS^{1,2}

H. D. CHAPMAN³ AND S. M. BROWN⁴

INTRODUCTION

IN A PRECEDING PAPER (3)⁵ an account is given of the development of phosphorus deficiency in citrus trees growing in one of two soils potted in 55-gallon containers. In the other soil an acute deficiency of sulfur occurred. The purpose of this paper is to describe the effects of this sulfur deficiency on the growth, appearance, fruit characters, and inorganic composition of the orange trees of this experiment. To the knowledge of the authors, sulfur deficiency of citrus trees growing in the field has never been recognized or described. Haas (7) has given a very brief description of sulfur deficiency of young Valencia trees grown in sand cultures. He states that this deficiency caused a chlorosis of the leaves. Total sulfur determinations in the leaves, twigs, root bark, and rootlets showed less of this constituent in the plant grown without sulfate than in corresponding plants of the same age growing in an adjacent nursery. The leaf symptoms illustrated, however, are unlike those produced on the experimental plants described in this paper.

EXPERIMENTAL PROCEDURE

The technique used in these experiments, as regards culture, differential fertilization, number of containers, and preliminary cropping, has been given in the accompanying paper (3), and only such details as appear necessary to an understanding of this paper are set forth herein.

The soil in which sulfur deficiency developed was obtained from a sagebrush-covered hillside on the property of the University of California Citrus Experiment Station at Riverside. It was derived from granite and is classified as a Sierra loam. This soil was initially used for purposes of comparison with the phosphorus-deficient Hanford fine sandy loam. Previous pot tests on the Sierra soil, while showing a low supply of total and available nitrogen, had given no hint of other deficiencies.

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² Paper no. 437, University of California Citrus Experiment Station, Riverside, California.

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⁴ Assistant Chemist in the Experiment Station.

⁵ Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

As noted in the paper on phosphorus deficiency (3, table 1), enough soil was obtained to fill twelve 55-gallon containers. Six treatments in duplicate were accorded this soil, as follows: cultures 13 and 14, no treatment; cultures 15 and 16, calcium nitrate; cultures 17 and 18, calcium nitrate and dicalcium phosphate; cultures 19 and 20, calcium nitrate and potassium sulfate; cultures 21, 22, 23, and 24, calcium nitrate, dicalcium phosphate, and potassium sulfate. The dicalcium phosphate and potassium sulfate were mixed throughout the soil at the rate of 4,784 pounds of P_2O_5 , and 1,185 pounds of K_2O per acre, save for cultures 23 and 24, which received P_2O_5 at the rate of 9,568 pounds per acre.^a The calcium nitrate was applied in solution at the rate of 482 pounds per acre to the surface of the soil in the beginning, and frequent additions were made subsequently during the course of the experiment. No further applications of phosphate or potassium were made, but as noted later, subsequent additions of sulfur and of calcium sulfate were accorded to some of the cultures for diagnostic purposes. The cultures were watered with distilled water throughout.

After a preliminary cropping with oats, one-year-old budded navel-orange trees were planted in the containers on March 4, 1935.

DEVELOPMENT AND DIAGNOSIS OF SULFUR DEFICIENCY

While none of the orange trees in the Sierra loam grew quite so well as those in the Hanford fine sandy loam, little effect from fertilizer additions was evident for the first three years save for extreme nitrogen deficiency in cultures 13 and 14 and a very slight growth response from the potassium sulfate treatments in cultures 19, 20, 21, 22, 23, and 24. In the spring of 1938, however, the new growth on all the trees was distinctly yellowish. It was thought that this might be the result of insufficient aeration and failure of the plant roots to absorb adequate nitrogen; poor water penetration into this soil had been noticed almost from the beginning, free water often standing on the surface for several days after an irrigation.

To determine whether the physical state of this soil could be improved, 27 grams of sulfur per culture (equivalent to a rate of 946 pounds per acre on an area basis) was mixed into the top 2 or 3 inches of soil of half the replicated cultures of this series (nos. 16, 18, 20, 22, 24) on July 18, 1938. Within a few weeks, the yellow foliage of the sulfur-treated trees began to turn green; and shortly thereafter, healthy, vigorous new growth appeared. The untreated trees showed no improvement.

^a Rate per acre calculated on an area basis. The soil-surface area in oil drums was 2.74 square feet.

Since the effects of sulfur on soils are diverse, and the results noted could have been caused by the improved physical condition of the soil or by the effects on nutrient availability, further experiments were undertaken.

To determine the characteristic effects of sulfur deficiency, a sand-culture experiment of the automatically operated type (4), using sweet-orange and grapefruit seedlings and lemon plants grown from cuttings, was begun in the greenhouse. One sand-culture unit was provided with a complete nutrient solution of a type known to be suitable for good citrus growth, and another with a sulfate-deficient nutrient solution in which the sulfate-carrying salts were replaced by nitrates. After a growing period of about six months, the terminal foliage of all plants in the cultures lacking sulfate became yellow, the affected leaves being more or less uniformly yellow, as in nitrogen deficiency. The older green leaves, however, retained their green color to a somewhat greater degree than when nitrogen is lacking. The appearance of these sulfur-deficient plants at this stage was strikingly similar to that of the navel-orange trees in the soil cultures, especially at periods following the emergence of new-cycle growth.

Soil samples taken from the soil cultures in September, 1938, were extracted with water, and tests for sulfate were made on the filtered solution. Substantial quantities were found in those soils which had been treated with sulfur, but only a trace in the untreated soils.

In the spring of 1939, the new-cycle growth on the non-sulfur-treated trees was again very yellowish, as in the previous year.

On June 21, 1939, several clusters of such yellowed leaves from tree 19 were sprayed with a 2-N solution of sodium sulfate. Within a few weeks some green spots appeared on these leaves, whereas there was no change in the untreated yellowed leaves.

On July 9, 1939, 28 grams of calcium sulfate (equivalent to a rate of 981 pounds per acre applied on an area basis) was applied to the surface of the soil of one of the chlorotic tree cultures (no. 19). In the course of the summer, the yellowish leaves of the tree in this culture became green, while the leaves of the untreated trees remained essentially unchanged.

In order to further verify the belief that the malnutrition of these trees was sulfur deficiency, total sulfur and nitrogen determinations were made on terminal yellow leaves and old green leaves picked from the affected navel-orange trees (no. 15), as well as on corresponding leaves from the sulfur-deficient sweet-orange seedlings grown in the greenhouse. For comparison, leaves of comparable age from one of the now healthy, sulfur-treated trees (no. 16), growing in Sierra loam,

from one of the nitrogen-deficient trees (no. 14) growing in this soil, and from control cultures growing in the greenhouse were also analyzed. The results are presented in table 1. The sulfur and nitrogen contents of the leaves of the navel-orange trees suspected of sulfur deficiency were very similar to those of the leaves of known sulfur-deficient plants grown under controlled conditions in the greenhouse. Despite the nearly identi-

TABLE 1
SULFUR AND NITROGEN CONTENTS OF LEAVES FROM HEALTHY
AND YELLOWED CITRUS PLANTS

Source, age, and character of leaves tested	Composition of leaves, in percentage of dry matter	
	Total sulfur	Total nitrogen
	<i>per cent</i>	<i>per cent</i>
Sulfur-deficient sweet-orange seedlings grown in greenhouse:		
Young terminal yellow leaves.....	0.075	3.88
Old green leaves.....	.120	3.31
Healthy sweet-orange seedlings grown in greenhouse:		
Young terminal green leaves.....	.260	3.46
Old green leaves.....	.220	3.15
Chlorotic navel-orange trees grown in Sierra loam soil:		
Young terminal yellow leaves.....	.096	2.54
Old green leaves.....	.120	2.44
Nitrogen-deficient navel-orange tree grown in Sierra loam soil:		
Young terminal yellow leaves.....	.180	1.12
Old yellow leaves.....	.320	1.13
Healthy sulfur-treated navel-orange tree grown in Sierra loam soil:		
Young terminal green leaves.....	.202	2.15
Old green leaves.....	0.320	1.66

cal appearance of leaves affected by lack of nitrogen and those affected by lack of sulfur, it will be noted that the nitrogen content of the sulfur-deficient leaves is a little higher than that of healthy green leaves, whereas the sulfur content is, roughly, one half that of leaves from healthy plants.

In the spring and summer of 1940, the non-sulfur-treated trees (that is, those which had received neither sulfur nor calcium sulfate) again produced an extremely yellowish cycle of growth which was even more marked than in the two preceding years. On May 29, 1940, 100 grams of calcium sulfate was incorporated into the soil surface of another of the sulfur-deficient tree cultures (no. 17). In one month's time, the yellow leaves of this tree had become green. Subsequently, healthy new-cycle growth emerged, and this tree now stands in sharp contrast to the untreated trees.

All these observations prove that the malnutrition which developed in these trees was acute sulfur deficiency.⁷

EFFECT OF SULFUR DEFICIENCY ON TREE GROWTH AND FOLIAGE

As already mentioned, the onset of sulfur deficiency was shown by the appearance of a decidedly yellowish type of new growth. The typical appearance of young terminal leaves and of older leaves on the same

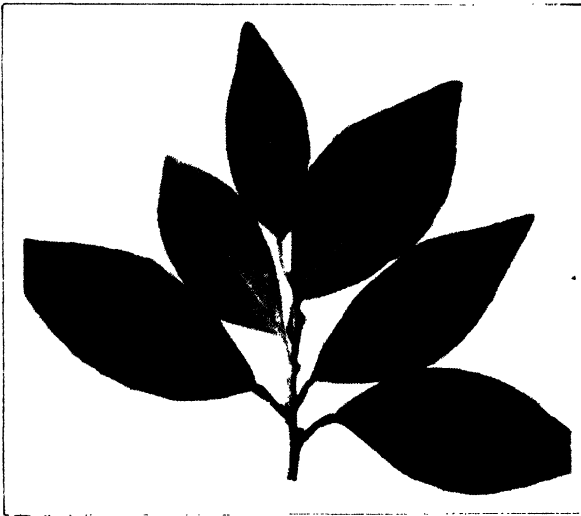


Fig. 1.—Shoot from a sulfur-deficient navel-orange tree (no. 15), showing yellow new-cycle leaves which stand in sharp contrast to the green older leaves. This type of growth is especially prominent in the earlier stages of sulfur deficiency. The yellow sulfur-deficient leaves are similar in appearance to nitrogen-deficient leaves. In many instances the midrib is somewhat more yellow than the rest of the leaf.

shoot, at the time when this disorder first became manifest, is shown in figure 1. The terminal growth was distinctly yellow, though there was no leaf pattern other than a tendency for the midrib to be a little more yellow than the mesophyll tissues. The chlorotic terminal growth stood in sharp contrast to the older green leaves during the first month or so

⁷ It is curious that sulfur deficiency should have developed at the same time and to the same degree in cultures 19, 20, 21, 22, 23, and 24, which received potassium sulfate initially. One explanation is that most of the sulfate had been leached out of the surface by the frequent additions of distilled water before the trees were planted in this soil. As noted previously, a preliminary crop of oats was grown in these soils prior to planting the trees. Another possibility is that some of the sulfate may have been reduced and disappeared as hydrogen sulfide in the periods following an irrigation, when water often stood in these soils for several days at a time.

after the appearance of the new-cycle growth. As the yellow leaves aged, they gradually became somewhat greener, and the contrast with subsequent new cycles of growth was less conspicuous. The leaves became leathery and thickened and finally attained a dull-green color; the mid-ribs on many were more yellow than the rest of the leaf.

The new growth which appeared in 1939 and 1940 was more yellow than that of the preceding year, and the leaves were smaller. The appearance of the sulfur-deficient tree no. 23, in June, 1939, is shown in plate 1, *A*. The dull-green color of the old leaves, many of them with a somewhat more yellowish midrib, is shown in plate 1, *C*, in contrast with leaves from a healthy tree (plate 1, *B*). The spring-cycle growth in 1940 consisted essentially of an exceedingly profuse though weak bloom, scarcely any leaves accompanying this bloom (plate 1, *D*). No fruit was set, and considerable dieback of these twigs subsequently took place. The cream-colored June-cycle growth which followed is shown in plate 1, *E*. The leaves were small and immature. Subsequently, with hot weather, considerable burn took place, both at the leaf tips and in other parts of the leaf. Such burn is not uncommon with citrus leaves which, for one cause or another, are lacking in chlorophyll. Many of these June-cycle leaves had dropped by September.

Save for considerable dieback, no abnormal twig, branch, trunk, or root symptoms, such as splitting or gumming, have occurred.

EFFECT OF SULFUR DEFICIENCY ON FRUIT

While only one of the sulfur-deficient trees (no. 21) bore fruit in 1940-41, most of them produced a few fruits each during the year 1939-40. All of these fruits had definite color characteristics in common. In place of the deep-green color of healthy immature fruits, those on the sulfur-deficient trees were of a light yellowish-green color throughout their early development, in this respect paralleling the chlorotic appearance of leaves (see plate 2, *A*). Maturing fruits started to turn color at about the same time as those on the healthy trees but failed to develop the orange color of the healthy fruit. Instead, they were of a distinctly lemon-yellow hue. Some of the fruits were small and misshapen; many of them attained normal size, however.

Examination of the interiors of affected fruits revealed, in many, an incomplete development of the juice vesicles and, in some, a distinct gelatinization of the contents. Most of such fruit had a somewhat thickened rind. Cross sections of healthy and sulfur-deficient fruits are shown in figure 2. Not all the fruits were so seriously affected as the one illustrated, but nearly all showed more or less rind thickening and some gelatinization of the juice-vesicle contents. The exterior appearance of

immature fruits and the exterior and interior of mature healthy and sulfur-deficient fruits are shown in plate 2. The similarity of some of these characters to the condition known as "granulation" (2) is rather marked. Whether there is any necessary connection is unknown.

Determinations of the acid and soluble-solids content of the juice of

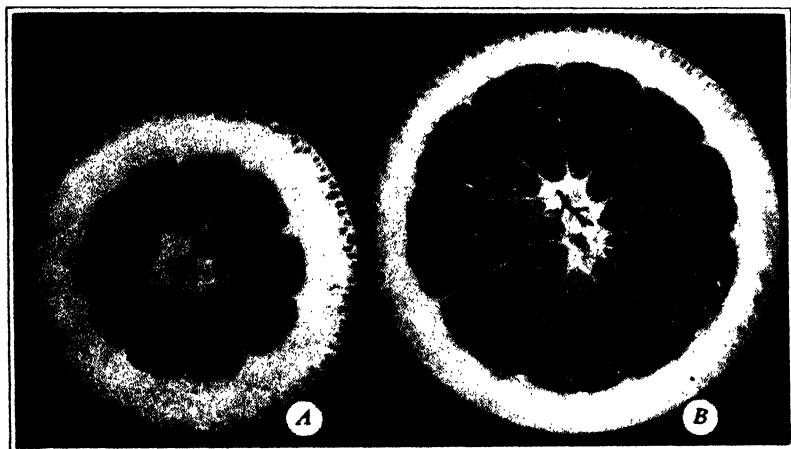


Fig. 2.—Cross sections through center of mature (A) sulfur-deficient and (B) healthy navel oranges. Note thickened rind and shriveled juice vesicles of sulfur-deficient fruit. This is a somewhat extreme case; not all the fruit from the sulfur-deficient trees was so adversely affected (see plate 2).

mildly affected fruit revealed a low sugar content but no significant difference in acid, in comparison with healthy fruit of like age. There was a noticeable lack of oil in the rind of the sulfur-deficient fruit.

INORGANIC COMPOSITION OF SULFUR-DEFICIENT ORANGE TREES

In July, 1940, one of the sulfur-deficient trees (no. 15) was removed from the culture, and inorganic analyses were made. The methods of sampling and analyzing were identical with those described in the preceding paper (3). The results, compared with those obtained from analyses of similar parts of a healthy tree, are presented in table 2.

All parts of the sulfur-deficient tree were lower in sulfur than corresponding parts of the healthy tree. The greatest contrast in total sulfur in the two trees was found in the bark and wood of the twigs, trunk, and coarse roots. The younger leaves showed a lower sulfur content than the older leaves.

Total nitrogen of all parts of the tree lacking sulfur was higher than that of the healthy tree. This difference was especially marked in the old

leaves. Since there is a decided similarity in the appearance of sulfur- and nitrogen-deficient leaves, analysis affords a decisive means of distinguishing between them: the leaves of nitrogen-deficient trees, as

TABLE 2
COMPARATIVE INORGANIC COMPOSITION OF PARTS OF SULFUR-DEFICIENT AND
HEALTHY NAVEL-ORANGE TREES

Part of tree and condition	Constituents of dry matter, at 105° C								
	Ash	Ca	Mg	K	Na	Cl	N	P	S
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Young leaves:									
Sulfur-deficient.....	16.02	3.56	0.22	3.40	0.210	0.35	4.90	0.50	0.050
Healthy.....	14.23	4.34	.12	1.55	.020	.39	3.38	.18	.230
Old leaves:									
Sulfur-deficient.....	15.40	5.05	.18	0.81	.100	.42	5.30	.34	.130
Healthy.....	22.80	8.17	.09	0.80	.040	.35	1.70	.11	.260
Twig bark:									
Sulfur-deficient.....	12.25	4.32	.13	0.34	.010	.12	3.03	.10	.010
Healthy.....	15.47	5.22	.12	0.62	.005	.14	1.65	.28	.270
Twig wood:									
Sulfur-deficient.....	5.31	1.89	.06	0.15	.010	.09	0.85	.01	.004
Healthy.....	4.12	1.26	.08	0.24	.004	.14	0.72	.22	.120
Trunk bark:									
Sulfur-deficient.....	12.83	4.23	.25	0.29	.005	.07	2.12	Trace	.010
Healthy.....	13.15	4.40	.35	0.66	.005	.11	1.64	.24	.180
Trunk wood:									
Sulfur-deficient.....	3.32	1.10	.07	0.17	.004	.12	0.73	Trace	.010
Healthy.....	2.49	0.69	.08	0.21	.003	.14	0.60	.16	.110
Root bark:									
Sulfur-deficient.....	8.75	2.56	.12	0.61	.006	.35	2.66	.22	.040
Healthy.....	11.00	3.26	.18	0.75	.020	.40	2.15	.24	.200
Root wood:									
Sulfur-deficient.....	1.78	0.52	.09	0.09	.009	.14	0.70	.06	.008
Healthy.....	2.64	0.73	.09	0.18	.005	.12	0.66	.16	.080
Fine roots:									
Sulfur-deficient.....	13.73	4.04	.21	0.54	.010	.39	2.81	.30	.080
Healthy.....	28.23	4.46	0.22	0.59	0.040	0.32	1.95	0.25	0.140

shown in table 1, are distinctly subnormal in nitrogen content and somewhat higher in total sulfur, whereas the reverse is true when the yellowing results from lack of sulfur.

With other mineral elements, results were not always consistent in different parts of the tree. The leaves and fine roots of the sulfur-deficient plant were distinctly higher in phosphorus content, than those of the healthy plant. The condition was reversed, however, in the bark

and wood of twigs, trunk, and coarse roots, the phosphorus content being distinctly lower in the sulfur-deficient than in the healthy plant parts, that of the trunk being as low as in phosphorus-deficient trees. The potassium content of the young sulfur-deficient leaves was abnormally high; but in the bark and woody tissue it was lower than in corresponding parts of the healthy tree. The calcium and total-ash content were, for the most part, lower in the sulfur-deficient than in the healthy tree.

In general, there is a decided parallelism in the nitrogen, potassium, calcium, and total-ash contents of these sulfur-deficient trees and the phosphorus-deficient trees discussed in a previous paper (3). One point of difference is the relatively lower sulfur content of young leaves as compared with old leaves of the sulfur-deficient tree. Under conditions of phosphorus deficiency, the young leaves are higher in phosphorus than the old leaves. This is in harmony with the observation that in sulfur deficiency the young growth is the first to be affected, whereas in phosphorus deficiency the older leaves are the first to show the effect.

DISCUSSION

The external effects of sulfur deficiency on bearing citrus trees agree in many respects with those described by other investigators on a wide range of plants. General yellowing of the foliage, especially of the terminal growth, and a resemblance to nitrogen deficiency are the more prominent characters emphasized. The similarity of symptoms of sulfur deficiency of citrus to those of tea plants, as reported by Storey and Leach (10), is marked: the undersized, yellow, uprolled, tipburned young leaves and their premature abscission followed by twig dieback, as seen on tea plants, are also characteristic of citrus trees. These investigators found that absorption of potassium sulfate, magnesium sulfate or sodium sulfate by cut shoots brought about prompt recovery. While this treatment has not as yet been tried with citrus trees, leaves sprayed with a solution of sodium sulfate developed green spots. Recovery after soil application of sulfate was rapid.

McMurtrey (8) noted on sulfur-deficient tobacco plants a yellowing of the leaf midrib and veins analogous to that seen on the citrus trees here described. In connection with vein yellowing, however, it should be noted that this frequently occurs in citrus leaves from other causes. Substantial root or bark destruction due to disease, gopher, or mechanical injury are common causes. The sulfur-deficient leaves which show this symptom, while of shorter life than healthy leaves, do not fall so early or abruptly as do leaves which become affected with the vein chlorosis caused by root rot or other troubles.

Though no studies of organic composition were made on the affected citrus trees, Nightingale, Schermerhorn, and Robbins (9) and Eaton (5), in studies of the metabolism of sulfur-deficient plants, found accumulations of carbohydrates, nitrates, and proteolytic products. Eckerson (6) noted that lack of sulfur decreases the reductase of soybean and tomato plants.

A thickening of cell walls of sulfur-deficient plants was found by Nightingale, Schermerhorn, and Robbins (9) and by Eaton (5). The thickened and leathery leaves which developed on the citrus plants may be a reflection of excessive lignin formation.

The parallelism between sulfur and phosphorus deficiencies, noted by the aforementioned workers as manifest in carbohydrate and nitrate accumulations, is also apparent in the inorganic composition of citrus plants affected by the two deficiencies. The promptness of the recovery of sulfur-deficient plants when sulfur is supplied is noteworthy and is no doubt owing, in part, to the accumulations of carbohydrate and nitrate, which are important foundation materials for the synthesis of proteins and other vital plant constituents.

The development of sulfur deficiency in citrus grown in Sierra loam cultures has raised the question whether commercial citrus orchards in any part of California might be lacking in this element. Considerable areas in certain parts of Oregon, Washington, and California are low in sulfur, and crops respond to additions of this element. Few citrus groves are likely to benefit by sulfate fertilization, however, for the following reasons. In the first place, all irrigation waters carry more or less dissolved sulfate; and while those waters derived from the runoff of the essentially granitic-type mountainous areas are low in sulfate content, the renewal is frequent, and citrus-tree requirements for sulfur are rather low.⁸ Also, a certain amount of sulfur is brought down annually by rainfall. And Alway, Marsh, and Methley (1) have shown that air, even in regions remote from industrial centers, contains a small amount of sulfur dioxide, part of which is absorbed by the soil and by growing crops. In addition, any organic matter added to the soil in the form of manures, straws, and so forth, will furnish available sulfur, as will ammonium sulfate or mixed fertilizers carrying potassium sulfate or superphosphate. Pest-control operations employing dusting sulfur or sulfur-containing insecticides add to the sulfur supply of soil. Hence, even on citrus soils low in sulfur, deficiencies are not likely to develop under California conditions, except perhaps in isolated instances where waters of low-sulfate content prevail and no sulfur or sulfur-containing

⁸ Computations based on analyses of whole fruits show that a yield of 20,000 pounds of fruit per acre would remove about 25 pounds of sulfur.

compounds are used in the commercial production of citrus. In conclusion, it should be noted that many California citrus soils and irrigation waters, for example, those of Imperial, Orange, and Ventura counties, are high in sulfate content.

SUMMARY

A condition of malnutrition which developed gradually in young navel-orange trees growing in a granitic-derived soil in large 55-gallon containers was found to be sulfur deficiency. This disorder was characterized by an abnormal yellowing of the new-cycle growth, similar to the more or less uniform yellowing caused by nitrogen deficiency. In many of the leaves, the midrib was somewhat more yellowish than the rest of the leaf.

In contrast to nitrogen-starved leaves, sulfur-deficient leaves had a higher nitrogen content than is normal for healthy green leaves and a lower sulfur content, whereas nitrogen-deficient leaves had a subnormal nitrogen content and a slightly higher sulfur content. Thus it is possible by leaf analysis to differentiate definitely between sulfur and nitrogen deficiency.

With the exception of considerable dieback, no abnormal twig or bark symptoms developed on the trees lacking sulfur. While growth was limited, as with phosphorus-deficient trees, a profuse, though weak, bloom was a characteristic feature. This may be a result of carbohydrate accumulation, since different workers have shown that one of the effects of sulfur deficiency in a number of plants is an accumulation of starch and other forms of carbohydrate.

In place of the deep-green color of healthy immature fruits, those produced on the sulfur-deficient trees were of a light yellowish-green color; and maturing fruits failed to develop the orange color characteristic of fruit produced on healthy trees. They were, instead, distinctly lemon yellow in color. Most of the sulfur-deficient fruit showed abnormally thick rinds and reduced juice content. In many of the fruits, the juice vesicles were shriveled; in the less severely affected fruit, the contents of many of the juice vesicles were gelatinized, as in granulation.

Inorganic analyses of leaves, twigs, trunk, and roots of a sulfur-deficient tree were made. The sulfur-deficient leaves showed, in general, a higher nitrogen, phosphorus, potassium, and magnesium content and a lower calcium and sulfur content than the leaves from a healthy tree of like age. Except for the young leaves, the ash content of all parts of the tree was less in the sulfur-deficient tree. A certain degree of parallelism in the composition of sulfur-deficient and phosphorus-deficient orange trees is apparent.

Though many western soils are low in total sulfur, it does not appear probable that, except in isolated instances, commercial citrus orchards would benefit by sulfate fertilization. Not only do irrigation waters carry more or less dissolved sulfate, but small increments are also brought down by rains; these supplies added to the sulfur or sulfur-bearing compounds used incident to fertilization and pest control probably more than meet citrus-tree requirements.

ACKNOWLEDGMENTS

The authors are indebted to Mr. David Rayner for effective work rendered in the culture and care of the experimental trees; they are also indebted to Mr. George F. Liebig, Jr., and Mr. Basil Followell for miscellaneous help given from time to time. This assistance is acknowledged with thanks.

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PLATES

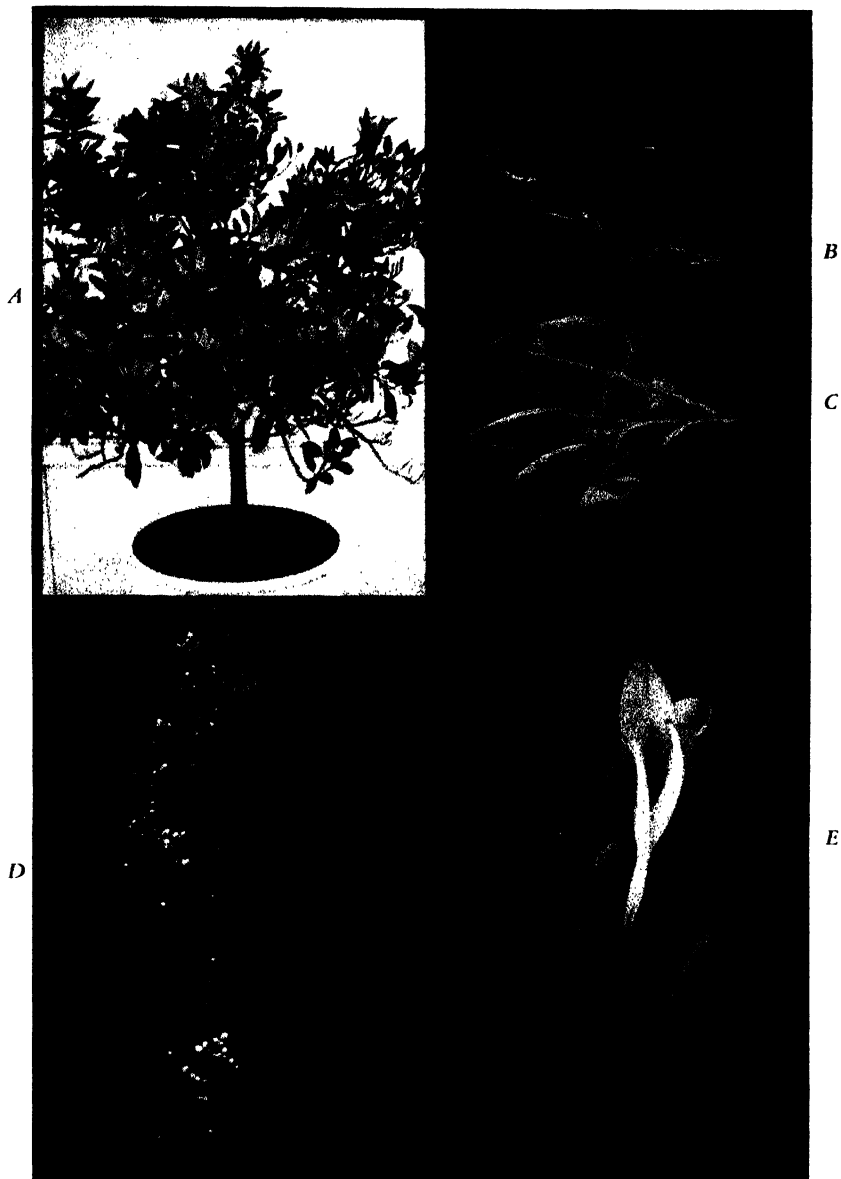


Plate 1.—Sulfur deficiency of navel-orange tree: *A*, four-year-old tree showing chlorotic new-cycle growth and dull-green old leaves (June, 1939); *B*, healthy shoot; *C*, sulfur-deficient shoot showing dull-green leaves with yellowish midribs and weak new-cycle spring growth; *D*, spring-cycle growth (1940) showing profuse but weak bloom; *E*, extremely chlorotic sulfur-deficient June-cycle growth which emerged after the spring bloom. (Note upright position on stem, small leaves, and tipburn.) These yellow leaves showed progressive burning on the tips and margins and, in some leaves, brown necrotic spots in mesophyll areas. Many of these June-cycle leaves had fallen by September.

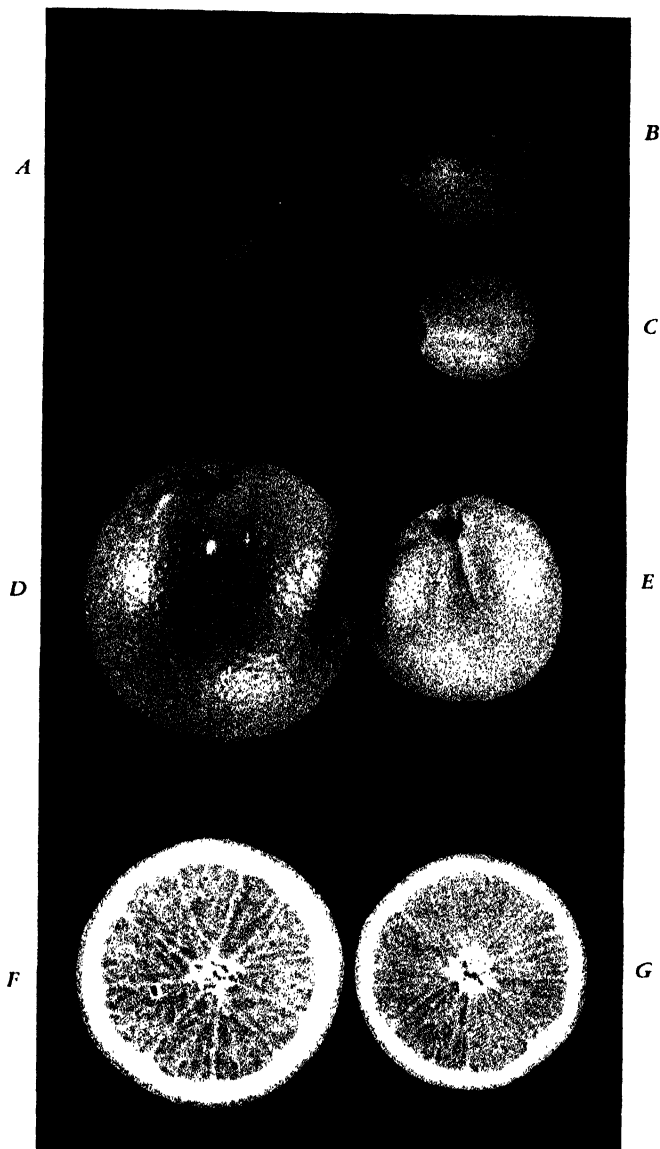


Plate 2.—Sulfur-deficient and healthy navel oranges. Immature (six-month-old) fruit (A) from healthy tree and (B, C) from sulfur-deficient tree. The lemon-yellow color of mature sulfur-deficient fruit (E) is shown in contrast with the orange color of mature healthy fruit (D). Cross sections show gelatinization of contents of juice vesicles of sulfur-deficient fruit (F) in comparison with healthy fruit (G).

**SPECIES OF STIGMINA AND STIGMELLA
OCCURRING ON PLATANUS**

DONALD J. SMITH AND CLAYTON O. SMITH

SPECIES OF STIGMINA AND STIGMELLA OCCURRING ON PLATANUS^{1,2,3}

DONALD J. SMITH⁴ AND CLAYTON O. SMITH⁵

INTRODUCTION

THE FOUR OR FIVE species of *Platanus*, or plane trees, commonly known as "sycamores" in the United States, occur widely throughout North America, Europe, and Asia. These trees are notable for their picturesque beauty in their natural habitats and are widely planted for use as ornamentals on lawns and along streets. Their foliage, however, is subject to attack by various fungi, among which are species of *Stigmina* and *Stigmella*. These closely related conidial fungi possess oval to oblong brown spores, whose distinguishing characteristics are the transverse septa in those of *Stigmina* sp. and the muriform septa in those of *Stigmella* sp. These fungi have been reported to cause the production of lesions on the leaves of *P. orientalis* L., *P. occidentalis* L., and *P. racemosa* Nutt. The diseases which they cause are not of major importance, for they do not seriously threaten the destruction of the trees. In certain localities, however, and in certain seasons, the leaf spots are conspicuously abundant, and affected trees are prematurely defoliated.

Most plant pathologists and mycologists who have collected specimens of *Stigmina* and *Stigmella* on *Platanus orientalis*, *P. occidentalis*, and *P. racemosa* have regarded the pathogens as one and the same species, that is, *Stigmina Platani* (Fekl.) Sacc. But, when this study was begun in December, 1935, at the University of California Citrus Experiment Station, it soon became apparent that the identity and nomenclature of these fungi were in a confused state. For this reason, a comparative study of *Stigmina* and *Stigmella* on *Platanus* was undertaken.

ORGANISMS INVOLVED

Three related but distinct fungi have been shown to be involved in these diseases: *Stigmella Platani-racemosae* Dearn. and Barth. *apud* Dearn. on *Platanus racemosa*, in California; *Stigmina Platani* (Fekl.)

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² Paper no. 438, University of California Citrus Experiment Station, Riverside, California.

³ The major part of this paper is based on a thesis by the senior author submitted in partial fulfillment of the requirements for the degree of Master of Science, University of California, 1937. (Typewritten.) Copy on file in the Library of the University of California, Berkeley. The present paper includes further research undertaken, after the thesis was completed, in coöperation with the junior author.

⁴ Graduate student at the Citrus Experiment Station, 1935 to 1937.

⁵ Associate in the Experiment Station; retired July 1, 1941.

Sacc. on *P. orientalis*, in Europe; and a species of *Mycosphaerella* on *P. occidentalis*, in the southeastern and southern central United States.

The third fungus was described as a new species by Wolf (24)* and named *Mycosphaerella Stigmia-Platani*, in the belief that it was the perithecial stage of *Stigmia Platani*. This *Mycosphaerella* has an unnamed polymorphic conidial stage, some of whose conidia are typical of the genus *Stigmia*, others of *Cercospora*, and still others intermediate in shape between these two types. Polymorphism in the conidial stage is indicated by Wolf (24, fig. 8). The conidial stage of *Stigmia Platani* does not show polymorphism. The evidence from pathogenicity, appearance of the disease, physiological characteristics, and morphology of the conidial stage, discussed later in the paper, indicates that the conidia of the *Mycosphaerella* on *Platanus occidentalis* are distinct from those of *Stigmia Platani* and that the *Mycosphaerella* described by Wolf (24) is apparently not the perithecial stage of *Stigmia Platani*.

It seems advisable, therefore, to reject the name *Mycosphaerella Stigmia-Platani* Wolf as untenable, according to the *International Rules of Botanical Nomenclature* (9), which states:

Art. 64. A name of a taxonomic group must be rejected if the characters of that group were derived from two or more entirely discordant elements, especially if those elements were erroneously supposed to form part of the same individual.

In its place, the name *Mycosphaerella polymorpha* is proposed, with the following description:

Mycosphaerella polymorpha n. n.

Mycosphaerella Stigmia-Platani Wolf (24, p. 60-61) *nomum confusum*.

Perithecia in vernali in putrescentibus foliis efformantia, hypophylla per totum folium dense dispersa, punctiformia, nigra, erumpenti-immersa, sphaeroidea, 65-85 μ diam.; aseis sacciformibus, fasciculatis, octosporis, apophysatis, 55-70 $\times$ 9-11 μ ; sporidiis biserialis, loculis inaequalibus, loculo superiore crassiore, hyalinis, rectis vel curvulis, 8-19 $\times$ 4-7 μ .

Spergoniis autumnis efformantibus, numerosis, hypophyllis, innatoprominulis, paginis inferioribus ex toto vel in maculis exaridis occupantibus, ovatis vel globosis, nigris, 55-65 μ ; spermatibus bacilliformibus, 2-3 $\times$ 1 μ , hyalinis.

Hab. in foliis dejectis *Platani occidentalis*.

Status conidicus: Statum conidicum *Stigmia polymorpha* n. n. sistit. Caespitulis hypophyllis, atris, primo maculiculis deinde subeffusis; conidiis polymorphicis, stigmioideis vel cercosporoideis, 14-70 $\times$ 3-11 μ , intense olivaceis, 1-8-septatis, non-constrictis; conidiophoris fasciculatis, fusciculis. Hab. stato conidico non modo in pagina inferiore *Platani occidentalis* parasitico sed in foliis vivis *Platani racemosae*, *P. Wrightii*, atque *P. acerifoliae*, in Amer. bor.

There remains, as will be indicated in this report, the possibility that the pathogen *Mycosphaerella polymorpha* on *Platanus occidentalis* has

* Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

been confused with *M. platanifolia* (Cke.) Wolf. *M. platanifolia* was first described from leaves of *P. occidentalis* by Cooke (3) as *Sphaerella platanifolia*, and its conidial stage is stated by Wolf (24 and 25) to be *Cercospora platanicola* Ellis and Everhart (5).

Whether the organism identified by Saccardo (20) as *Stigmina Visianica* Sacc. is correctly named, has been questioned by Bubák (2, p. 219), who says:

Bei einem amerikanischen Exemplare dieses Pilzes (Claremont bei Los Angeles in Süd-Kalifornien, *Platanus racemosa*, leg. Baker) finde ich sehr oft auch Sporen mit einer Längswand, so dass die Unterschiede zwischen *Stigmella* und *Stigmina* nicht allzu fest sind.

Die zweite europäische Art *Stigmina Visianica* Sacc. ist von *St. Platani* nicht verschieden. Schon Lindau . . . weist auf diesen Umstand hin. Ich finde die Sporen bei beiden genannten Arten sehr variabel und gleich gross. Demnach ist *Stigmina Visianica* Sacc. nur ein Synonym zu *Stigmina Platani* (Fuckel) Saccardo.

A specimen from the Farlow Herbarium, bearing the notation "*Stigmella Visianica* Sacc. ? if it is different from *Stigmina Platani* f. Ellis. Pine Hills, Illinois, September 1884," was examined by the writers and found to be similar to the fungus on *Platanus occidentalis*, herein identified as *Mycosphaerella polymorpha*.

HISTORY AND DISTRIBUTION OF THE FUNGI

The name *Stigmina Platani* was employed by Saccardo in 1878 (18) and in 1880 (19) for an organism called, as early as 1815, *Puccinia Platani* Bivona. Later, Saccardo (20) used the name *Stigmina Platani* also to replace that of *Stigmella Platani* Fuckel, employed by Thümen (22) for the same organism. Specimens of this fungus had been sent from Greece to Thümen and transmitted by him to Fuckel, who, in 1873, named the fungus *Stigmella Platani*. That it occurs elsewhere in Europe is evidenced by the fact that Saccardo (20) records it from Germany, Bubák (2) from Tirol (Austria) and Istria (Italy), and Nattrass (13) from Cyprus.

The fungus now known as *Stigmella Platani-racemosae* was stated by Harkness (7), who collected it on *Platanus racemosa* near Niles, in Alameda County, California, to have been present in California as long ago as 1885; and its presence in this state was mentioned by McClatchie (12, p. 376) in 1897. Both Harkness and McClatchie called it *Stigmina Platani*, however, in the belief that it was identical with the organism occurring in Europe on *P. orientalis*. Apostolides (1), in 1929, studied this disease in California and also identified the causal fungus as *Stigmina Platani*. In the same year, Dearness and Bartholomew (Dearness, 4) described this pathogen as *Stigmella Platani-racemosae*, recognizing

that the leaf-spot fungus on *P. racemosa* was distinct from *Stigmina Platani* and basing their description upon specimens collected at Riverside, California. Specimens in the Claremont College herbarium (Baker's collection no. 3956), identified as *Stigmina Platani* on *P. occidentalis*, were examined by the writers and found, also, to be *Stigmella Platani-racemosae* on *P. racemosa*.

To date, *Stigmella Platani-racemosae* is not known to occur outside of California. Through correspondence with interested collectors, the writers have determined that the fungus is present in the following counties in southern California: San Diego, Los Angeles, Orange, Riverside, San Bernardino, Santa Barbara, and Ventura. It has not been collected in the northern part of the state except by Harkness (7).

The fungus *Mycosphaerella polymorpha* is of widespread occurrence on *Platanus occidentalis* in the southeastern and southern central United States, especially in the valleys of the lower Ohio and lower Mississippi rivers. Among the early records of the occurrence of this fungus (under different names) is that of Jennings (10) in 1890, in Texas; Tracy and Earle (23, p. 116) in 1895, in Mississippi; Patterson (14, p. 31) in 1902, in Illinois. Later, Hoffer (8) and Pipal (15) recorded its occurrence in Indiana. And in 1925, Martin (11, p. 380) reported that the conidial stage of this organism on *P. occidentalis* had been collected in Arkansas, Georgia, Illinois, Indiana, Iowa, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, Texas, and West Virginia.

The writers have examined specimens of *Mycosphaerella polymorpha* from Arkansas, Illinois, Mississippi, Missouri, North Carolina, and Oklahoma, and have found them all to be specifically identical and distinct from *Stigmina Platani* from the Old World and also from *Stigmella Platani-racemosae* from California.

MATERIALS USED

The materials used in these studies were from many different sources. Herbarium specimens of leaves were generously loaned by Claremont College, Claremont, California, and by Dr. D. S. Welch, of Cornell University. Herbarium specimens and information were provided by the Farlow Library and Herbarium, Harvard University; by the University of California Herbarium, Berkeley; and by the University of California Citrus Experiment Station, Riverside. Freshly pressed leaves of *Platanus occidentalis* affected by *Mycosphaerella polymorpha* were received from Dr. Frederick A. Wolf of Duke University; and leaves of *P. orientalis* affected by *Stigmina Platani* were received from Dr. R. M. Nattrass, Mycologist, Nicosia, Cyprus. Leaves of *P. racemosa* affected by *Stigmella Platani-racemosae* were collected by the writers in California.

The species of *Platanus* used in the inoculation experiments were: (1) *P. orientalis*, trees grown from seed sent by Professor P. Th. Anagnostopoulos, Superior School of Agriculture, Athens, Greece; (2) *P. Wrightii* S. Wats., trees grown from seed and cuttings from Dr. R. B. Streets, University of Arizona; (3) *P. occidentalis*, trees grown from cuttings from Dr. Carroll W. Dodge of the Missouri Botanical Garden, and trees from local nurseries; (4) *P. acerifolia* Wild (hybrid), trees from local nurseries; and (5) *P. racemosa*, trees from local nurseries and trees growing on the Citrus Experiment Station campus.

APPEARANCE OF THE DISEASES

Both macroscopic and microscopic differences may be employed in distinguishing these diseases.

Macroscopic Appearance.—Leaf-spot disease on *Platanus racemosa*, caused by *Stigmella Platani-racemosae* (fig. 1, A-C), is manifested by the presence of small, effuse, black-colored areas, 1 to 3 mm in diameter, on the lower surfaces of the leaf blades and on the stipules. These areas generally increase in diameter to about $\frac{1}{2}$ cm, but the entire lower leaf surface may become blackened because of numerous secondary infections. The blackening is produced by the abundance of conidiophores and conidia. If the lesions are widely scattered, the spots may gradually enlarge to 1 cm in diameter. The leaf tissues immediately above the fungus (fig. 1, A) are at first yellow, but later become brown and necrotic. The margins of the spots are usually definite, irregular, and surrounded by green tissue.

Lesions on *Platanus orientalis* caused by *Stigmina Platani* (fig. 1, F), as observed on herbarium material from Cyprus, are very similar in general appearance to the spots on *P. racemosa* caused by *Stigmella Platani-racemosae*. The two diseases can best be distinguished by comparative microscopic examination of the conidiophores and conidia (see "Microscopic Appearance," below.)

Lesions produced by the conidial stage of *Mycosphaerella polymorpha* are at first pale-green, indefinitely limited areas, if viewed from the upper leaf surface. Thin, weblike gray stippled areas (fig. 1, D) cover the corresponding areas on the lower leaf surface. When the disease has progressed to the extent that a large proportion of the upper leaf surface is pale green, the entire lower leaf surface may be invested with an effuse gray coating (fig. 1, E) of conidia and conidiophores. At this stage, which may have developed by midsummer, the trees will appear blighted, and defoliation will have begun.

Microscopic Appearance.—Sections of lesions caused by *Stigmella Platani-racemosae* on *Platanus racemosa* show the fungus to be localized

at first in the stomatal chambers (fig. 2, I). Later, hyphae are produced that ramify between the cells; these may extend throughout the tissues to the upper epidermis. Mycelia and haustoria were not found within the cells when sought in paraffin sections or in freezing microtome sec-

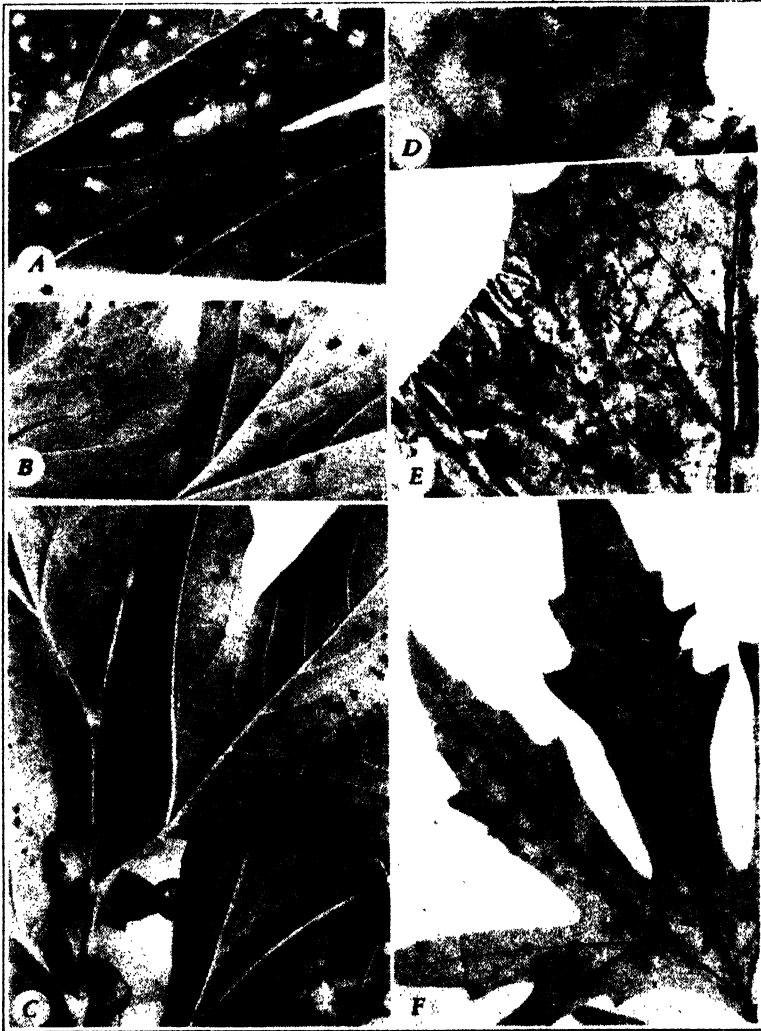


Fig. 1.—Natural infection on leaves of *Platanus* spp.: A–C, *Stigmella Platanii-racemosae* on *P. racemosa*—A, showing as spots on upper leaf surface; B, on lower leaf surface; C, on lower leaf surface and on stipules. D, E, *Mycosphaerella polymorpha* on lower leaf surfaces of *P. occidentalis*. F, *Stigmia Platani* on lower leaf surface of *P. orientalis* (from Cyprus).

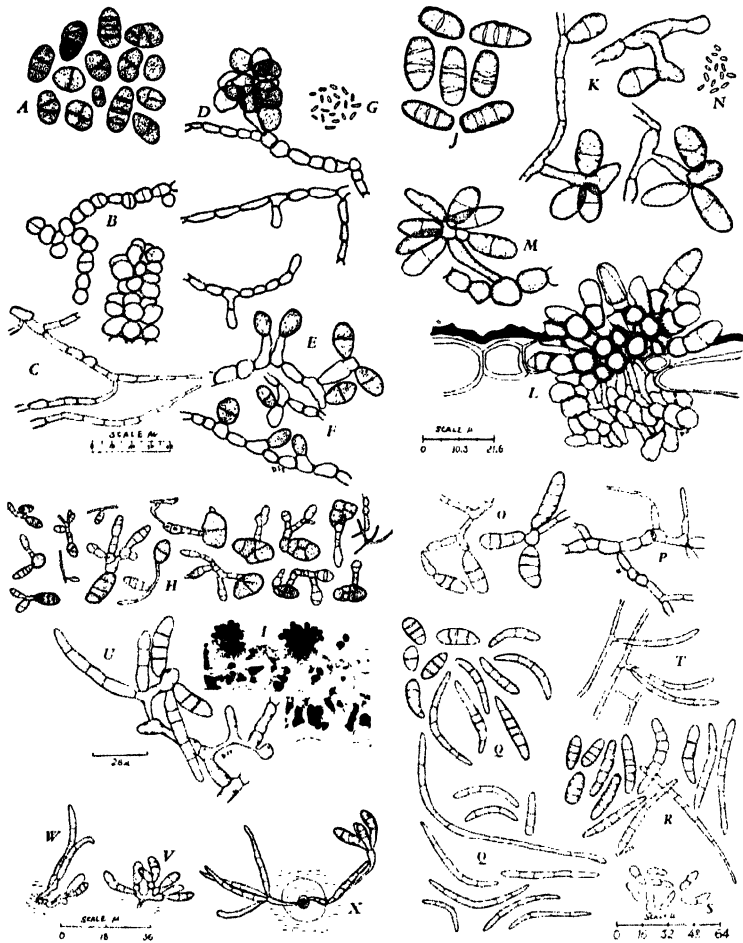


Fig. 2.—Camera-lucida drawings of spores and mycelium of species of *Stigmina* and *Stigmella* on *Platanus* spp.

Stigmella Platanis-racemosa from *Platanus racemosa*, A–I: A, conidia; B, mycelium thick, dark and massed; C, mycelium hyaline and slender; D, attachment of spores to mycelium; E, F, mycelium, conidia, and conidiophores, showing spore formation; G, spermatia from pure culture; H, spore germination in drops of water on slides (germinating spores gave rise to additional spores, but attempt at repetition of these results was unsuccessful); I, section showing conidia and conidiophores growing out of stomatal chambers ($\times 305$).

Stigmina Platanis orientalis, J–N: J, spores from type species; K, spores and mycelium produced on Czapek's-agar film on slide; L, section of living material; M, spores, showing attachment; N, spermatia from pure culture growing in leaf juice on filter paper.

Mycosphaerella polymorpha from *Platanus occidentalis*, O–X: O, *Stigmina*-type spores from culture from single-spore isolation of *Cercospora* type, growing in leaf juice on slide, after 21 days; P, mycelium from same culture; Q, *Cercospora*- and *Stigmina*-type spores from an infection on *P. racemosa* by an isolate from a single *Cercospora* spore, after 56 days; R, dark-colored, subhyaline spores of *Stigmina* and *Cercospora* types from culture from single-spore isolation of *Stigmina* type on Czapek's agar; S, ascospores from a dead leaf; T, *Cercospora*-type spores from Czapek's-agar film on slide, after 21 days; U, sporulation, on slide, of growth from a single *Cercospora* spore, showing variation in spores attached to a conidiophore; V–X, spores from artificial inoculation on leaf of *P. acerifolia* (the culture used in this inoculation was from a single *Cercospora*-type spore from a single-spore-culture inoculation that had fruited only *Cercospora*-type spores)—V, showing variation in spores attached to a conidiophore; W, different types of spores attached to single hypha; X, mycelial growth from base of a leaf hair and two types of spores.

tions stained with the differential stains, safranin light-green, triple stain, or iron-alum—hemotoxylin, applied according to methods outlined by Rawlins (16). Conidia are produced singly on conidiophores from fascicles projecting through the stomata. Affected leaf tissue shows fewer chloroplasts than normal tissue.

A study of freehand sections of leaf spots caused by *Stigmina Platani*

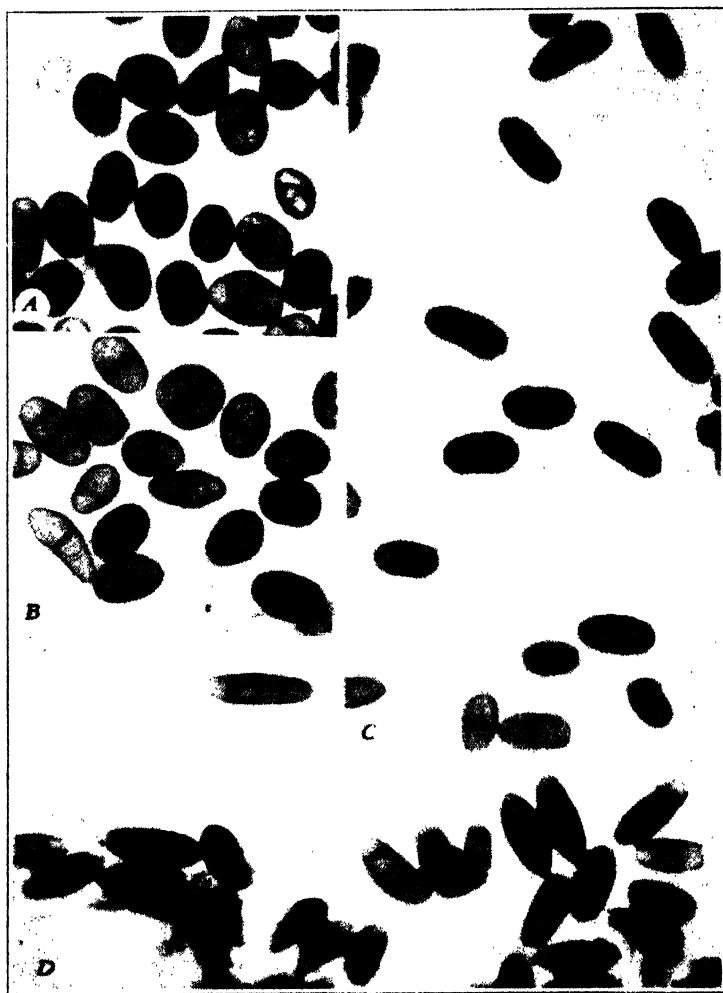


Fig. 3.—Photomicrographs of conidia of the three species of fungi: A, B, *Stigmella Platani-racemosae* from natural infection on *Platanus racemosa*, Riverside, California; C, *Stigmina Platani* from *P. orientalis* from Nicosia, Cyprus; D, *Stigmina* sp. (*Mycosphaerella polymorpha*) from Fungi Columbiana no. 2885 on *P. occidentalis* collected at Rogers, Arkansas. (All $\times 667$.)

on *Platanus orientalis* (fig. 2, *I*) and by *Mycosphaerella polymorpha* on *P. occidentalis* indicated that the relations of the pathogens to the diseased tissues in these species are similar to those found in *P. racemosa*.

The conidia of the three fungi, while somewhat similar in appearance, are sufficiently distinct to suggest three different species. The *Stigmina* type of conidia are oblong, dark-colored, septate bodies (fig. 3, *C*). The *Stigmella* type differed in having numerous irregular septations (fig.

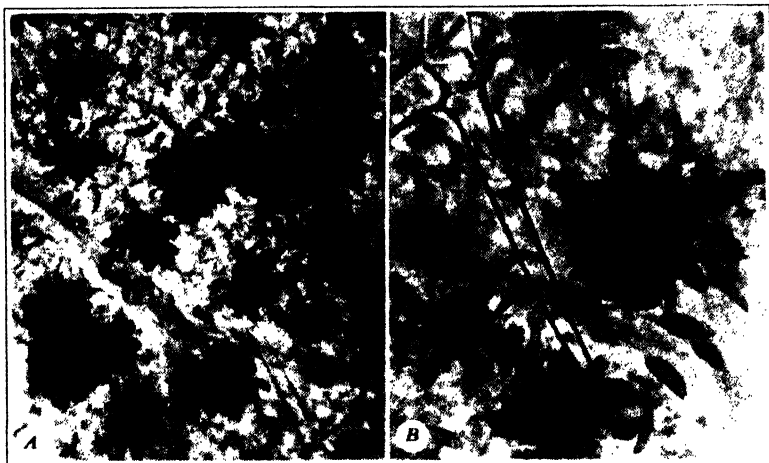


Fig. 4.—Fruiting of fungus on leaf of *Platanus racemosa*, from artificial inoculation with conidial spores of *Mycosphaerella polymorpha* taken from a diseased leaf of *P. occidentalis* from North Carolina: *A*, *Stigmina*- and *Cercospora*-type conidia shown in the same spore clusters ($\times 149$); *B*, fruiting of fungus ($\times 305$).

3, *A*, *B*). The conidia of *Mycosphaerella polymorpha* were variable in size and shape, as illustrated in figure 4 and in figure 2, *Q*, *R*, *T*, but often the *Stigmina* type (fig. 3, *D*) were the only ones to be found.

MORPHOLOGICAL COMPARISON OF THE THREE FUNGI

Conidial spores of the three fungi, *Stigmella Platani-racemosae*, *Stigmina Platani*, and *Mycosphaerella polymorpha*, taken directly from their respective primary hosts, show wide variation in size and septation (table 1 and fig. 2). While individual spores cannot always be identified with certainty as belonging to one or the other of these three species, conidia of each species, en masse, in spite of variations in septation and size, are sufficiently distinctive to make identification possible.

Conidia of *Stigmella Platani-racemosae* (figs. 2, *A*, and 3, *A*, *B*) are ovate to oblong, $10\text{--}22 \times 7\text{--}13 \mu$. Septations range from one to three cross

TABLE 1
COMPARATIVE SIZE AND SEPTATION OF SPORES OF *Stigmella* AND *Stigmia* FOUND ON *Platanus* SPP.

Species and source	Predominant type of spore*	Spores measured	Average			Minimum and maximum			Irregularly septate cell†
			Cells	Length	Width	Cells	Length	Width	
<i>Stigmella Platanus-racemosa</i> from California.....	<i>Stigmia</i>	number 35	number 3-43	microns 16.54	microns 10.64	number 1-5	microns 10-22	microns 7-13	number 9
<i>Stigmella Platanus</i> from Cyprus.....	<i>Stigmia</i>	50	2.94	18.77	8.75	2-4	14-24	7-11	1
<i>Stigmia</i> sp.† from North Carolina.....	<i>Stigmia</i>	51	4.40	22.24	8.91	3-9	14-45	7-11	2
<i>Stigmia</i> sp.† from North Carolina.....	<i>Cercospora</i>	52	5.23	47.78	4.54	3-7	17-70	3-6	0
<i>Stigmia Visianica</i> † from Illinois.....	<i>Stigmia</i>	35	5.23	24.21	8.55	2-6	13-34	7-10	1
<i>Stigmia Visianica</i> † from Illinois.....	Intermediate	6	5.83	34.00	7.46	4-7	26-43	6-9	0

* *Stigmia*-type spores are oblong, dark-colored, and septated (figs. 2, O, and 3, D); *Cercospora*-type spores are crescent-shaped, septated, and nearly hyaline (fig. 2, T); the "intermediate" type are those intermediate in shape between the *Stigmia* and *Cercospora* types.

† Irregularly septate spores are those that have a cross wall and other septa at an angle to the cross wall (fig. 2, A)—a muriform type of septation characteristic of *Stigmella*.

‡ Now considered to be a conical stage of *Mycosphaerella polymorpha*.

septa or from one to four diagonal or irregular septations. The abundant, irregularly septate spores distinguish this fungus from the fungi on *Platanus orientalis* (figs. 2, *J*, and 3, *C*) and on *P. occidentalis* (figs. 2, *O-T*, and 3, *D*).

Conidia of *Stigmina Platani* from *Platanus orientalis* are narrower, and some are longer than those of *Stigmella Platani-racemosae*, as indicated by the dimensions, $14-24 \times 7-11 \mu$, given in table 1. These spores rarely show the irregular septa characteristic of *Stigmella*.

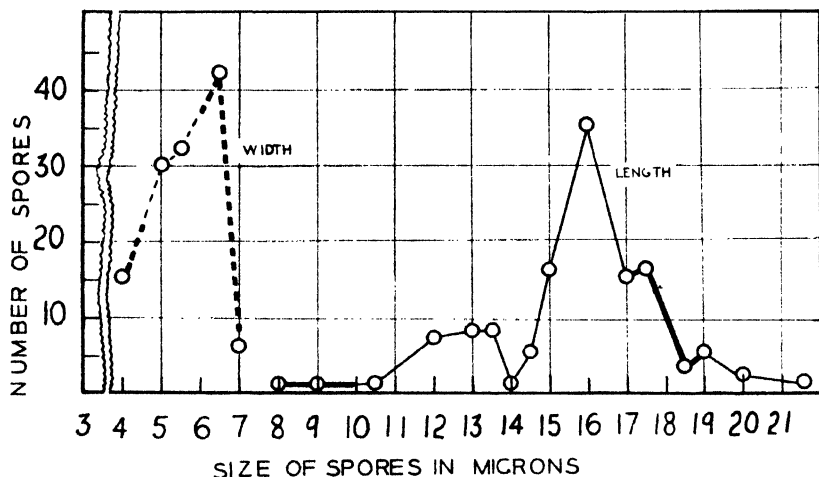


Fig. 5.—Frequency-distribution curves of measurements of 125 ascospores of *Mycosphaerella polymorpha*. Heavy lines indicate measurements corresponding with those of Wolf's (24) description of what he called *M. platanifolia* and *M. Stigmina-Platani*.

The *Stigmina*-type spores of *Mycosphaerella polymorpha* (figs. 2, *O*, and 3, *D*) are more elongate and have more acute ends than those of the two other species. They are oval, dark, thick-walled, and have been found to measure $14-45 \times 7-11 \mu$ (table 1). *Cercospora*-type spores are still more elongate, are light brown to dark brown in color, thinner-walled, and usually curved or crescent-shaped (fig. 2, *T*); they measure around $17-70 \times 3-6 \mu$, although spores 120μ in length have been found. Between these two types there are other spores intermediate in shape and size.

One hundred and twenty-five ascospores of *Mycosphaerella*, ejected from leaves into drops of distilled water suspended on the inside cover of a petri dish, were measured under an oil immersion; they ranged in size from $8-19 \times 4-7 \mu$. (Ascospores from the same leaves were ejected onto agar media for culture studies; see p. 219.)

A frequency-distribution curve (fig. 5) shows a number of spores of an intermediate size that apparently bridges the gap between the spore

sizes of *Mycosphaerella polymorpha* and *M. platanifolia* (Cke.) Wolf (24). Wolf¹ states, however, that two population curves are shown here (fig. 5), and that measurements of a larger number of spores should confirm this.

PATHOGENICITY

Inoculations of *Platanus* spp. with fungi of *Stigmella* and *Stigmia* spp. were made by the following procedures. (1) Conidia from the leaves or from pure cultures of the fungi were suspended in water. The fungus suspension was applied to the leaves and young shoots by means of either a camel's-hair brush or an atomizer. In nearly all of these tests, a paraffin-paper or cellophane bag or a bell jar was used as a covering to maintain moisture conditions favorable for infection. This protection also prevented fortuitous dissemination and spread of the fungi used in the inoculations. The paper bags (fig. 6, C) were not sealed but had their edges twice-folded and kept in place by means of paper clips. In preliminary experiments, it was found that injuries, such as perforations made with a pin, were not necessary for infection, for infections seldom occurred in the loci of injuries but were common between them. (2) Infected leaves were pinned to normal leaves, which were then covered with paraffin-paper or cellophane bags. This method was very satisfactory in moist weather. (3) Spores and bits of mycelium from single-spore cultures of each of the three organisms were placed on leaves enclosed in cellophane bags. Each of the three causal organisms was later recovered in pure culture from the artificially inoculated leaves. Results of the tests are given in table 2.

The fungus *Stigmella Platanis-racemosae* caused infection and spread rapidly both on *Platanus Wrightii* (fig. 6, E and F) and on *P. racemosa* (fig. 6, G-I). So far as can be determined, this fungus has not previously been reported on *P. Wrightii*. It failed repeatedly, however, to produce infection when inoculated on *P. orientalis*, *P. occidentalis*, and *P. acerifolia* (hybrid trees).

Inoculations with *Stigmia Platani* (Cyprus strain) from *Platanus orientalis* resulted in infection on *P. orientalis* (fig. 6, A), but were ineffective on *P. racemosa*, *P. Wrightii*, *P. occidentalis*, and *P. acerifolia*.

Ascospores and conidia of both *Stigmia* and *Cercospora* types of *Mycosphaerella polymorpha* from *Platanus occidentalis* produced infection on *P. occidentalis* (fig. 6, D), *P. racemosa*, *P. Wrightii*, and *P. acerifolia*, but no infections developed on *P. orientalis*. All inoculations with cultures from single conidia of the *Stigmia* type of *Mycosphaerella polymorpha* produced some spots on which the *Cercospora*-type conidia were

¹ Wolf, F. W. In letter to the senior author dated October 17, 1938.

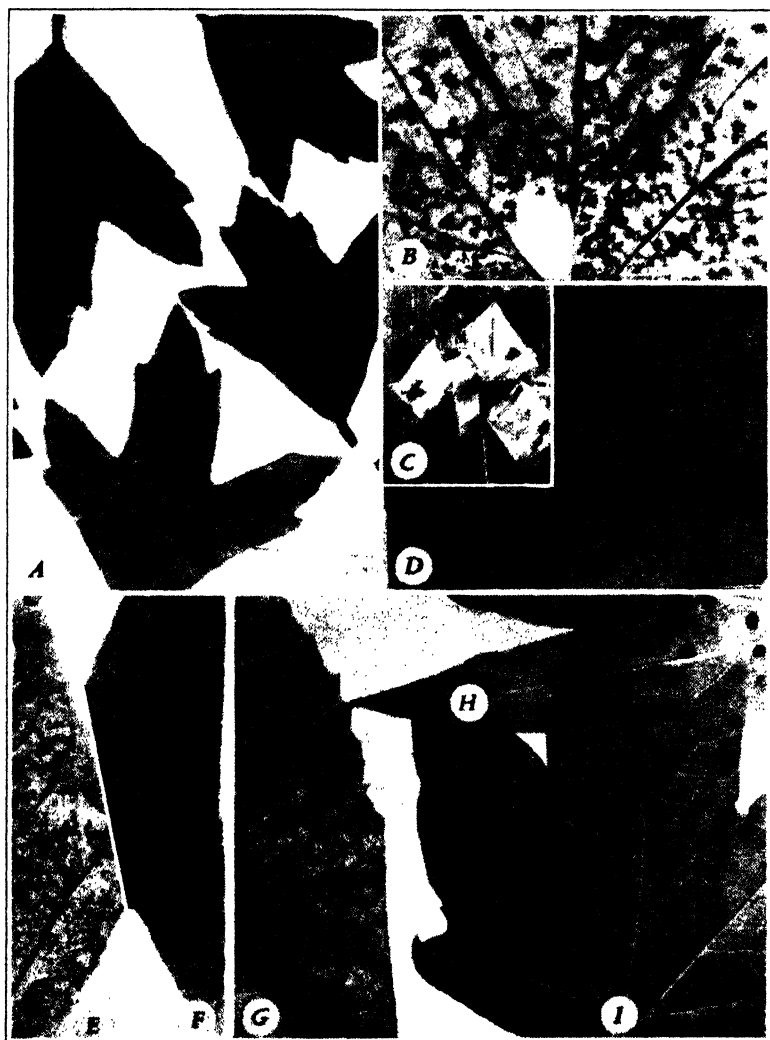


Fig. 6.—Artificial inoculations on species of *Platanus*: *A*, *Stigmina Platani* on young leaves of *P. orientalis*; *B*, *Mycosphaerella polymorpha* (from natural infection) on *P. racemosa*; *C*, inoculated leaves protected by paraffin-paper bags; *D*, *Mycosphaerella polymorpha* (culture from a single *Stigmina*-type spore isolated from *P. occidentalis* from North Carolina) on authentic leaf of *P. occidentalis*, where *Stigmina*- and *Cercospora*-type spores fruited in abundance; *E*–*I*, *Stigmella Platani-racemosae*—*E* and *F*, on upper and lower surfaces, respectively, of young leaf of *P. Wrightii*, after one month; *G*, on succulent leaf of *P. racemosa*, after one month; *H*, on normal leaf after three months; and *I*, after one month.

found. Most inoculations with *Cercospora*-type conidia produced some spots in which the *Stigmina*-type conidia were found. Usually a mixture of the two forms of conidia, together with conidia intermediate in form, was found on lesions resulting from single-spore inoculations. In some cases the fascicles bore *Stigmina*-type conidia only; in others, conidia of the *Cercospora*-type only; and in others, both types were formed on one and the same fascicle. Variations in conidia from single-spore cultures are shown in figure 2, U-X (p. 211).

TABLE 2
RESULTS OF INOCULATIONS OF *Platanus* SPP. WITH FUNGI OF
Stigmella AND *Stigmina* SPP.

Host	Single-spore inoculations					
	<i>Stigmella Platani-racemosae</i> from <i>Platanus racemosa</i>		<i>Stigmina</i> sp.* from <i>Platanus occidentalis</i>		<i>Stigmina Platani</i> from <i>Platanus orientalis</i>	
	Positive results	Negative results	Positive results	Negative results	Positive results	Negative results
<i>Platanus acerifolia</i>	0	5	8	0	0	8
<i>P. occidentalis</i>	0	9	4	3	0	10
<i>P. orientalis</i>	0	7	0	5	3	1
<i>P. racemosa</i>	10	0	10	5	0	8
<i>P. Wrightii</i>	7	0	5	3	0	4

* Conidial stage of *Mycosphaerella polymorpha*.

The minimum time from inoculation to the beginning of sporulation was about three weeks. In the cooler spring months, the period of incubation was from four to five weeks.

When the surface of leaves atomized with conidia of *Stigmella Platani-racemosae* was stained with safranin, germ tubes entering the stomata could occasionally be found. When surface growth on very young spots was removed, the substomatal areas were observed to be darkened. The absence of darkening elsewhere indicated that the fungus growth was confined to the stomatal areas. Stained paraffin sections of very young spots also showed the fungus localized in the stomatal cavities, with no growth elsewhere (fig. 2, I, p. 211). Infection was often abundant on the lower surface of uninjured leaves of *Platanus racemosa* that had been atomized with a spore suspension. These microscopic observations indicate that the pathogen penetrates by way of the stomata. Similar results were obtained with *Stigmina Platani* and *Mycosphaerella polymorpha*; so that each fungus appears to have the same mode of entrance into the leaves and the same type of subsequent growth within the substomatal tissues.

If susceptibility to infection is an index of relationship, artificial inoculations indicate that *Platanus racemosa* and *P. Wrightii* are closely related and that *P. occidentalis* is more closely related to the American species of *Platanus* than to the European, *P. orientalis*.

CULTURE STUDIES

Methods and Media.—The fungi were isolated in single-spore cultures by streaking suspensions of conidia on the surface of agar plates, where they could be observed in position under the high power of a binocular microscope; then by proper manipulation, single conidia could be picked up with a sharp needle and transferred to media in test tubes. Cultures from ascospores were obtained on agar in petri dishes inverted over moistened dead leaves, from the surface of which the perithecia protruded and discharged the spores onto the surface of the agar.

The media used, in the order of decreasing suitability for sporulation, were as follows: (1) *Platanus racemosa* leaf juice sterilized by filtration, (2) a special medium described by Smith and Smith (21) and made by the aseptic addition of an equal amount of the leaf juice to 4 per cent Czapek's agar, (3) Czapek's agar, (4) leaf-extract agar containing 3 per cent sucrose, (5) glucose potato agar, and (6) carrot plugs.

Filtered leaf juice was used both on slides supported on U-shaped glass rods in petri dishes and in Van Tieghem cells, for comparison of the sporulation of isolates from different types of spores. Living leaves were used for certain tests.

Results.—By these procedures, single-spore cultures of *Mycosphaerella polymorpha* were isolated as follows: 147 from *Cercospora*-type conidia, 165 from *Stigmina*-type conidia, and 76 from ascospores. Results of the tests are presented in table 3.

In other tests (not reported in table 3), 8 transfers from ascospore cultures of *Mycosphaerella polymorpha* onto Czapek's agar yielded 5 cultures that produced both *Stigmina*- and *Cercospora*-type spores, 1 culture that produced only *Cercospora*-type spores, and 2 that did not sporulate. Three isolates of *Cercospora*-type spores, when grown on Czapek's agar, yielded 2 cultures that produced only *Stigmina*-type spores and 1 that produced both *Stigmina*- and *Cercospora*-type spores.

Single-spore isolations of *Mycosphaerella polymorpha*, whether from conidia or from ascospores, produced on Czapek's agar two general types of colonies (fig. 7) about equal in number. One type was flat, light mouse gray to mouse gray (17); the other type was elevated and smaller in diameter than the first type under the same growing conditions. The color of the latter type was a similar gray, some colonies having white areas, however, and black margins (fig. 7). With age, a light-yellow

color sometimes appeared. When viewed from beneath, both types of colonies appeared dark olive-gray to olivaceous black (17). Colonies produced on glucose potato agar were usually much elevated and gray to black in color. On a basis of minor differences, the colonies could be

TABLE 3
SPORULATION OF *Mycosphaerella polymorpha* FROM SINGLE-SPORE ISOLATIONS
IN CULTURE MEDIA AND ON LEAVES OF *Platanus racemosa*

Type of spore isolated and medium inoculated	Total inoculations	Infections from different types of sporulation		
		<i>Cercospora</i> - type	<i>Stigmata</i> - type	Mixed, <i>Cercospora</i> and <i>Stigmata</i> *
	number	number	number	number
<i>Cercospora</i> :				
Living leaves (March, 1938).....	1	1	0	0
Living leaves (April, 1938).....	1	1	0	0
Living leaves (May, 1938).....	4	0	1	3C
Living leaves (June, 1938).....	9	3	1	5C
Living leaves (September, 1938).....	12	0	1	5C and 6S
Czapek's agar.....	16†	7	0	8C
Leaf juice on slides.....	3	2	0	1C
Leaf juice in Van Tieghem cells.....	6	0	0	6C
<i>Stigmata</i> :				
Living leaves (September, 1938):.....	11	0	0	6C and 5S
Czapek's agar.....	16†	10	0	6C
Leaf juice in Van Tieghem cells.....	6	0	0	6C
<i>Ascospore</i> :				
Living leaves (May, 1938).....	15	10	0	5C
Czapek's agar.....	74†	72	0	0
Leaf juice on slides.....	8†	1	0	5C
Leaf juice in Van Tieghem cells.....	4†	2	0	0

* The letters "C" and "S" indicate the type of spore (*Cercospora* or *Stigmata*, respectively) predominating.

† Isolates selected at random.

‡ Some of these inoculations failed to produce spores.

grouped into no less than fourteen different types. While occasional differences were noted in the size of spores produced by the different isolates, these variations could not be correlated with the kind of spore from which the culture originated.

Spermatia (fig. 2, *G* and *N*) of each of the three organisms developed both in cultures and on infected leaves. In cultures of *Mycosphaerella polymorpha*, dense mycelial masses developed containing these small bacilluslike bodies. But when these were streaked on nutrient media, no evidence of spermatial germination was obtained.

Of the 50 single-spore cultures of *Stigmella Platani-racemosae* made in these tests, 1 isolate produced a flat, spreading colony, when grown on

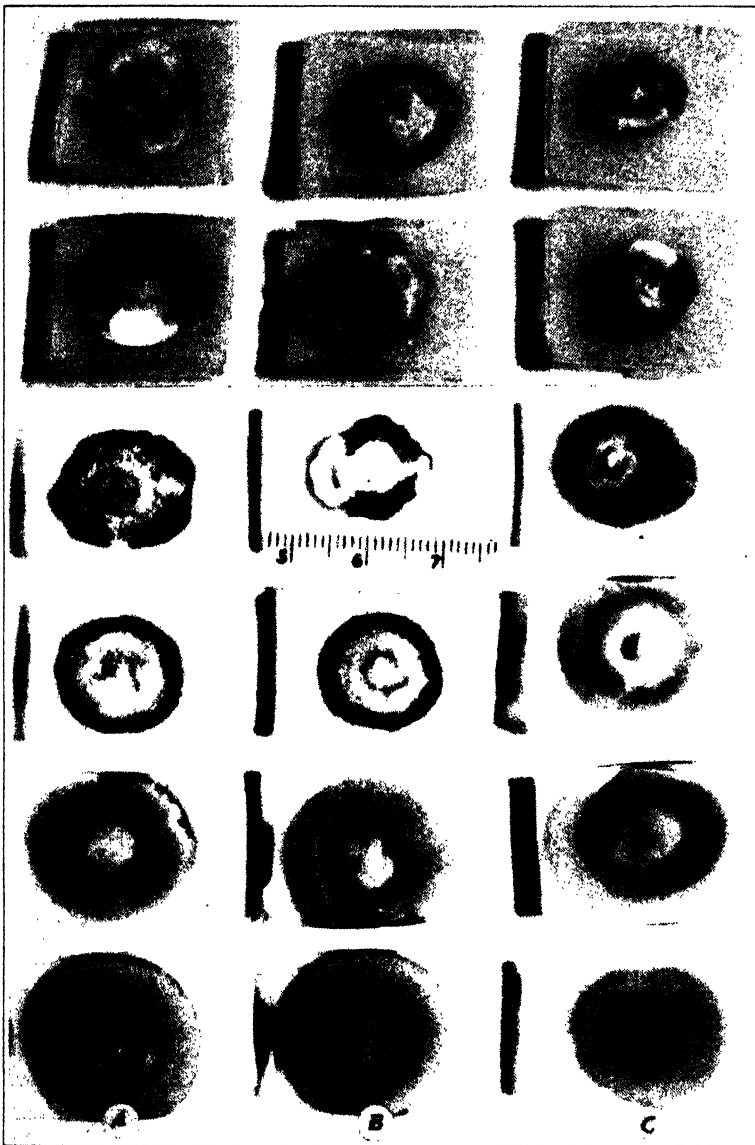


Fig. 7.—Colonies grown on Czapek's agar from single-spore culture isolations (different spore types) of *Mycosphaerella polymorpha*. The vertical rows show colony variation: A, colonies from *Ceroospora*-type spores; B, from *Stigmina*-type spores; C, from ascospores. The horizontal rows show colonies of similar types of growth.

glucose potato agar at room temperature; the other 49 produced colonies that were elevated.

The colonies of *Stigmina Platani* closely resembled those of *Stigmella Platani-racemosae* but were less variable than those of *Mycosphaerella polymorpha*.

TEMPERATURE RELATIONS

The effects of temperature on these three species of fungi were determined by the use of constant-temperature chambers having a range of 10°–35.5° C. A few tests were also made in a refrigerator at 5°. The

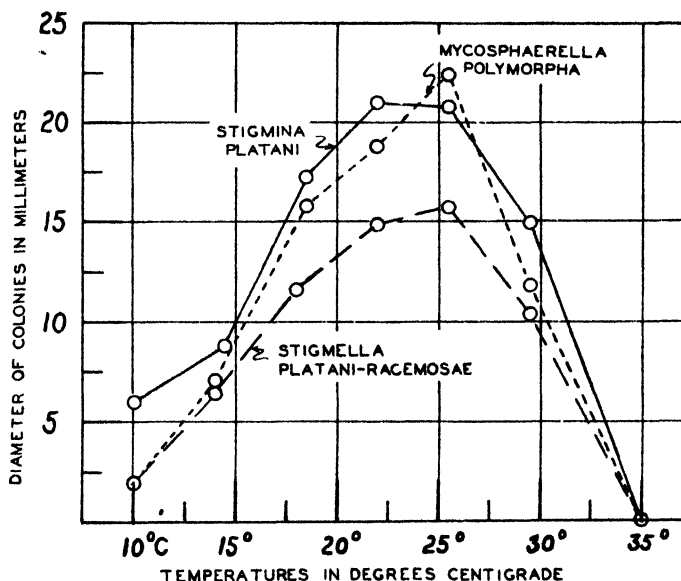


Fig. 8.—Growth response of colonies grown on glucose potato agar (pH 4.7) at different temperatures: *Stigmina Platani*, six weeks; *Stigmella* sp. (*Mycosphaerella polymorpha*), one month; *Stigmella Platani-racemosae*, one month.

diameter of colonies grown on glucose potato agar was used as an indicator of mycelial growth response. The optimum for all three organisms (fig. 8) was between 22° and 26°. They showed slight growth below 10°, but failed to grow at 35.5°. The growth curves of *Stigmella Platani-racemosae* and *Stigmina Platani* are flatter near the optimum than that of *Mycosphaerella polymorpha*. *Stigmella Platani-racemosae* gave the best sporulation between 14° and 19°; the other two fungi did not sporulate within this range during the time of the experiment.

The temperature at which the maximum germination of conidia of *Stigmella Platani-racemosae* and of *Mycosphaerella polymorpha* (fig.

9) took place (conidia of *Stigmina Platani* were not tested) agrees with that of the optimum temperature for growth of the mycelia of these two fungi. At 25° C, there was 75 per cent germination within 28½ hours, and 90 per cent within 47 hours. The count was based upon 50 spores selected at random. The germ tubes varied in length with the temperature; at 25° they reached an average length of 15.5 μ in 47 hours.

The thermal death points of the mycelia and spores of the three fungi were tested with cultures and conidia taken directly from the leaves of their respective hosts. Mycelium obtained from nonsporulating colonies

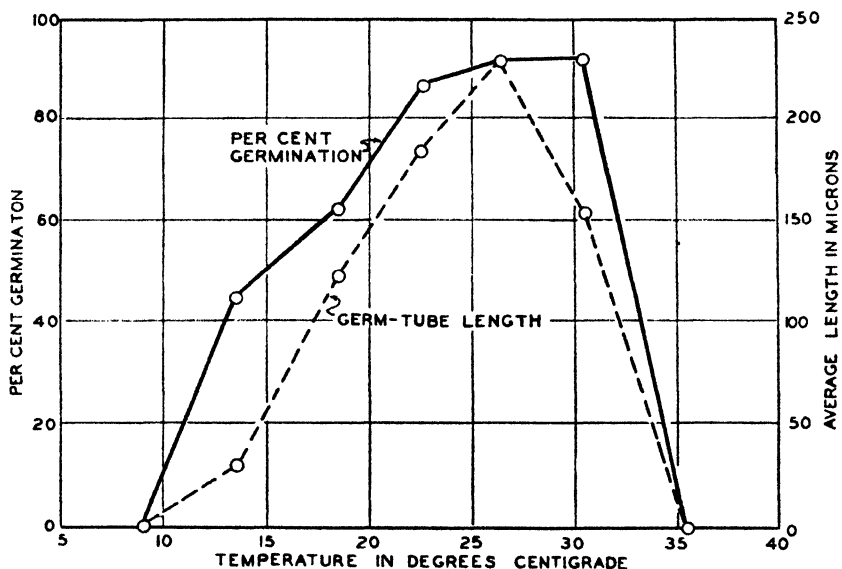


Fig. 9.—Spore germination and germ tube growth of *Stigmina* sp. (*Mycosphaerella polymorpha*) on glucose-potato-agar film on slides for 48 hours at different temperatures.

was broken into bits by means of a sterile rod. Concentrations of the suspensions of mycelia or conidia were adjusted by the addition of sterile water. These suspensions were put into sterile capillary tubes, 4 to 5 inches long, after which the tubes were sealed by means of a microburner. The temperature of the bath, which consisted of a large pan of water, was modified by means of a microburner. After exposure for a 10-minute period in the bath, the capillary tubes were surface-sterilized in mercury bichloride and washed in sterile water; the contents were then ejected upon glucose-potato-agar plates. Observations of the resultant growth were made at intervals of from one day to two weeks. The results of these tests are shown in table 4.

The thermal death point of mycelia and spores of both *Stigmella Platan-racemosae* from *Platanus racemosa* and *Stigmia Platani* from *P. orientalis* was found to lie between 45° and 46.5° C. The mycelium and spores of the *Stigmia* stage of *Mycosphaerella polymorpha* had a thermal death point between 47° and 48°, approximately 2° higher than that of the other two fungi.

Mycosphaerella was cultured in sterile leaf juice in Van Tieghem cells to test the influence of temperature on sporulation. Five cultures were

TABLE 4
DETERMINATION OF THERMAL DEATH POINT OF MYCELIUM
AND SPORES OF THE THREE FUNGI

Fungus growth treated	Effect of 10-minute treatments at different temperatures*					
	44° C	45° C	46° C	46.5° C	47° C	48° C
<i>Stigmella Platan-racemosae</i> from <i>Platanus racemosa</i> :						
Spores	+	+	+	—	—	—
Mycelium	+	+				
<i>Stigmia</i> stage of <i>Mycosphaerella polymorpha</i> from <i>P. occidentalis</i> :						
Spores	+	+	+		+	—
Mycelium	+	+	+		+	—
<i>Stigmia Platani</i> from <i>P. orientalis</i> :						
Spores	+	+	—	—	—	—
Mycelium	+	+		—		

* In the columns + = continued fungus growth indicated; — = no growth and probable death of the organism; blank spaces indicate that results at these temperatures were not recorded. For description of treatments see text (p. 223).

maintained at 15° C, 5 at 19°, 16 at room temperature (21°–33°), 5 at 26.5°, and 5 at 30.5°. Of the 16 cultures grown at room temperature, 6 originating from *Stigmia* spores produced a mixture of *Stigmia*- and *Cercospora*-type conidia; 6 originating from *Cercospora*-type spores also produced conidia of both kinds; 2 of the remaining 4 cultures, which originated from ascospores, produced *Cercospora*-type conidia only, and 2 remained sterile. Sporulation did not occur in any of the other cultures with the exception of one of those maintained at a temperature of 26.5°, which produced *Cercospora*-type conidia two weeks after inoculation.

Cercospora-type conidia were often found in cultures from the conidia (both *Cercospora*- and *Stigmia*-type) and ascospores of *Mycosphaerella polymorpha*, but were never found in cultures of *Stigmella Platan-racemosae* or of *Stigmia Platani*.

Results of inoculations with cultures from single spores on leaves of *Platanus racemosa* would seem to indicate that temperature may be a factor in determining the type of spore that will develop on the infected

leaf tissue (table 5). The production of the *Cercospora*-type was favored by the higher temperatures, and the *Stigmina*-type developed best at the lower temperatures.

HYDROGEN-ION RELATIONS

The hydrogen-ion relations of *Stigmella Platani-racemosae* and of *Stigmina Platani* were tested in carrot dextrose broth (fig. 10), on Czapek's agar, and on carrot dextrose agar. *Mycosphaerella polymorpha*

TABLE 5

SPORULATION FROM SINGLE-SPORE INOCULATIONS ON LEAVES OF *Platanus racemosa* WITH SPORES OF *Mycosphaerella polymorpha* UNDER DIFFERENT TEMPERATURE CONDITIONS; NOVEMBER—DECEMBER, 1938

Type of spore isolated and culture no.	Lathhouse, temperature variable*		Cool greenhouse, temperature 21°-27° C.		Warm greenhouse, temperature 27°-32° C.	
	Inoculations	Sporulation†	Inoculations	Sporulation†	Inoculations	Sporulation†
	number		number		number	
<i>Ascospore</i> :						
No. 5	1	S only	1	None	1	None
No. 11	1	S and C equal	1	None	1	None
No. 17	1	S only	1	None	1	None
No. 22	2	S only	2	None	2	C only
No. 23	2	None	2	None	2	C only
No. 34	2	Mixed, S predominant	1	S and C equal	1	C only
<i>Stigmina</i> -type:						
No. 227	1	S only	1	None	1	None
No. 239	1	None	1	None	1	Mixed, C predominant
<i>Cercospora</i> -type						
No. 115‡	1	None	1	Mixed, C predominant	1	None
No. 118	1	None	1	None	1	None
No. 130	1	None	1	None	1	Mixed, C predominant
No. 136	1	None	1	Mixed, C predominant	1	None

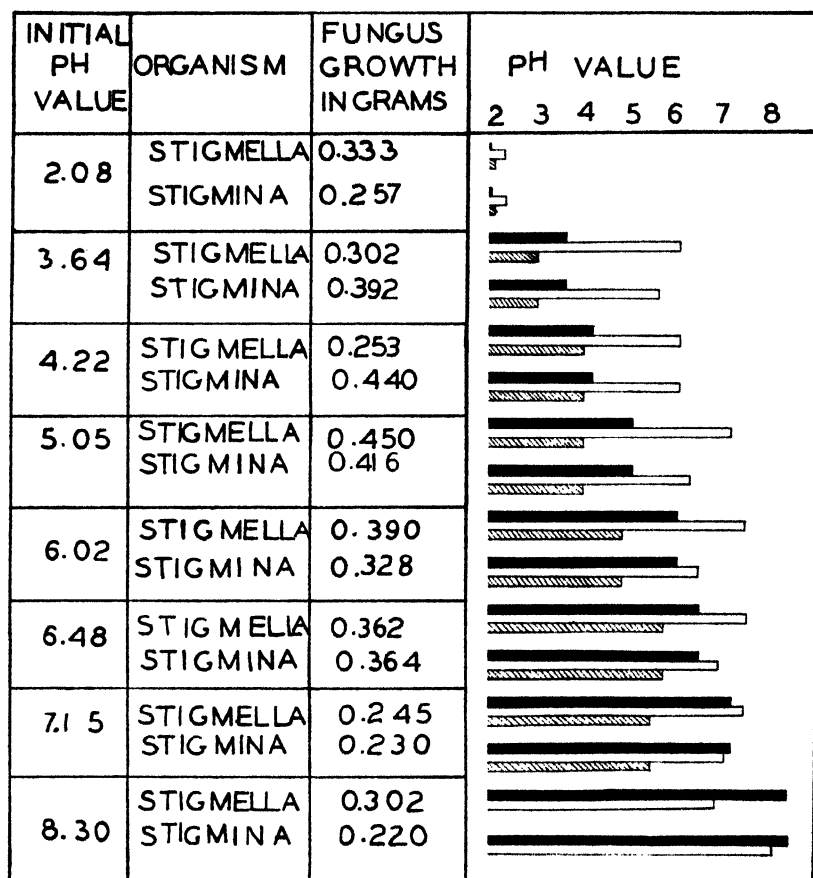
* No temperature records were taken for the lathhouse, but outside temperatures as recorded at the Citrus Experiment Station for November were: minimum, 2° C.; maximum, 20°; mean minimum, 4.3°; mean maximum, 24.6°. For December the minimum was 2°; maximum, 32°; mean minimum, 6.5°; mean maximum, 21.9°.

† The letters "S" and "C" indicate the type of sporulation, *Stigmina* or *Cercospora*, respectively.

‡ Organism isolated from inoculation by a previous single-spore culture.

was not tested. The fungi were grown in the liquid medium for three and one-half months and on the solid media for six weeks, at their optimum temperature of 25° C. In the cultures on Czapek's agar and on carrot dextrose agar, the minimum pH value was 2.0, the optimum 5.0, and the maximum between 7.0 and 8.0. Growth was slight at the alkaline end of the range. Growth of the fungi caused increased alkalinity in liquid cul-

tures, whereas the control liquids were more acid at the end than at the beginning of the experiment (fig. 10). There was little change in the pH value of the media where the initial concentration was pH 7.0.



INITIAL PH
 FINAL PH OF CONTROL
 FINAL PH WITH ORGANISM

Fig. 10.—Hydrogen-ion relations of *Stigmella Platani-racemosae* and of *Stigmina Platani* grown for three and one-half months on the surface of 100 cc of carrot dextrose broth in 200-cc flasks at 25° C. Control liquids contained no fungus inoculation.

Germination of spores and germ-tube length of *Stigmella Platani-racemosae* at different pH values, when tested in carrot-dextrose-agar drops on slides for 28 hours, showed maximum germination of approximately 85 per cent at pH 5.0. The germ-tube length, however, was great-

est at pH 4.5. At pH 5.0, the average germ-tube length was decreased by about one half of that at pH 4.5. The juice of leaf blades of *Platanus racemosa* had a pH value of 4.8 in April, as determined by the quinhydrone glass electrode; that of *P. acerifolia* gave a reading of pH 5.1 in September; there is, therefore, a close correlation between the pH of the leaf juice and that which is optimum for the pathogen.

CONTROL

The writers have conducted no experiments for control of the leaf spot on *Platanus racemosa*. The other two leaf spots are not found in California. Should control be found necessary, treatment with bordeaux mixture, as suggested by Felt and Rankin (6) in the control of *Gnomonia veneta* (Sacc. and Speg.) Kleb., which causes leaf and twig blight of plane tree, or sycamore, should be satisfactory. These writers recommend that the trees be sprayed with bordeaux mixture after the buds burst and before the leaves are half grown, and that a second application be given one week later. A third and fourth spraying at intervals of two weeks are suggested if the season is rainy. It is anticipated that burning the fallen leaves would lessen the severity of the initial infections and might well be a very important control measure.

DISCUSSION AND SUMMARY

On the basis of morphological and physiological differences and of host specificity, it is shown that three distinct species of fungi are involved in leaf spots on *Platanus* (plane tree). Each produces a different symptom complex and has a distinct geographical host range.

Stigmina Platani (Fekl.) Sacc. on *Platanus orientalis* L., from Europe, failed to infect other species of *Platanus*.

Stigmella Platani-racemosae Dearn. and Barth. is pathogenic to *Platanus racemosa* Nutt. in California. In pathogenicity tests it proved to be capable of infecting *P. Wrightii* S. Wats., not previously known to be susceptible. Other species of *Platanus* proved to be immune.

The fungus called, in this paper, *Mycosphaerella polymorpha* and found on *Platanus occidentalis* L., occurs in the southeastern and southern central United States. It was found to be pathogenic also on *P. racemosa*, *P. Wrightii*, and *P. acerifolia*, but not on *P. orientalis*. This organism produces polymorphic conidia that range in shape from those typical of *Stigmina* on the one hand, to those typical of *Cercospora* on the other. Conidia of each type and also of intermediate types may be borne on the same conidiophoral fascicle. This conidial stage has hitherto not been named, for the reason that it has been erroneously identified as *Stigmina Platani*.

The proper denomination of these three fungi could only be accomplished if their perfect stages could be developed under artificial conditions or were found to exist in the natural state on decaying leaves. The writers attempted unsuccessfully to induce the development of the perithecial stage of *Stigmella Platani-racemosae* under California conditions. Furthermore, at the request of the writers, leaves infected with *Stigmima Platani* were maintained in Cyprus under natural conditions, to permit the development of the perfect stage, but to no avail. Each of these organisms probably possesses a perithecial stage. Evidence for this is found in the fact that each possesses a spermatial stage, as previously noted (see "Culture Studies," p. 220). In the light of our knowledge of other ascomycetes, the production of spermatia may properly be interpreted as indicative of the presence of perithecia in the developmental cycle. The fact that these organisms can survive from year to year as conidial stages shows that the perfect stage is not essential to survival; but this is not proof of the nonexistence of a perfect stage.

The perithecial stages of *Mycosphaerella polymorpha* and *M. platanifolia* indicate that these species may be identical. The measurements for freshly discharged, hence mature, ascospores of *M. Stigmima-Platani* (*M. polymorpha*), given by Wolf (24, p. 58), are $17-19 \times 6-7 \mu$; and for those of *M. platanifolia*, $8-10 \times 4-4.5 \mu$. In the present study, the range of measurements of ascospores discharged from perithecia borne in leaves of *Platanus occidentalis* was $8-19 \times 4-7 \mu$, as previously stated (p. 215), and included spores 12.0, 13.5, 14.5, and 16μ long and 4.8, 5.4, and 5.6μ wide. These measurements indicate that there are spores intermediate in size between those published by Wolf for the two species of *Mycosphaerella*.

Wolf (24, p. 59) mentions two types of colonies: one type isolated from either the conidia or the ascospores of *Mycosphaerella Stigmima-Platani* (*M. polymorpha*) and the other type from either the conidia of *Cercospora platanicola* or the ascospores of *M. platanifolia*. But he states further* that the two types of colonies found in the present studies (see "Culture Studies," p. 219) and shown in figure 7 (p. 221) appear to have the same characteristics as those found in his studies.

Differences in appearance of colonies within one and the same species, however, are now known to be characteristic of an increasingly large number of fungi. The evidence in hand at present, therefore, as to the possible identity of *Mycosphaerella polymorpha* and *M. platanifolia* must be regarded as insufficient, and the solution of the problem must be left for future study.

* Wolf, F. A. In letter to the junior author dated August 10, 1940.

Unfortunately, Wolf (24) used the specific name *Stigmina-Platani* for the *Mycosphaerella* on *Platanus occidentalis*, whereas the present studies establish the fact that the conidial fungus *Stigmina Platani* is specifically distinct and occurs only on *P. orientalis*. This error, if preserved, would add to the nomenclatorial confusion, especially if the perithecial stage of *Stigmina Platani*, when discovered, should happen to be found to belong to *Mycosphaerella*, as this genus is now delimited. It has been deemed advisable, therefore, to reject the name *Mycosphaerella Stigmina-Platani* Wolf, and the new name *Mycosphaerella polymorpha* is proposed in its place.

Stigmina Visianica Sacc. appears to be identical with the conidial stage of *Mycosphaerella polymorpha*.

Each species has been isolated and grown in single-spore culture. Sporulation in culture was best induced by growth on *Platanus* leaf juice sterilized by filtration and on Czapek's agar.

Temperatures within the range of 22° to 26° C were found to be optimal for growth of each of the three species.

Germination of spores and mycelial growth occurred best in media having an acidity of approximately pH 5.0.

Removal of fallen leaves and spraying of the trees may be anticipated to be effective control measures.

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RELATION BETWEEN AUCTION PRICES AND SUPPLIES OF CALIFORNIA FRESH BARTLETT PEARS^{1,2}

SIDNEY HOOS³ and S. W. SHEAR⁴

INTRODUCTION

A PRIMARY PURPOSE of the present study is to present more factual information than heretofore has been available on certain characteristics of the price behavior of California Bartlett pears. Special attention is given to particular relations within the complex of pear prices, and various influences that enter into the determination of auction market prices are analyzed and discussed. A secondary purpose of the study is to present some analytical background that is necessary in order to view the recent development of the California fresh Bartlett pear industry and understand its present status. Therefore this discussion of California Bartlett prices, shipments, and relations to other fruits may be considered as a means of emphasizing and elucidating some of the problems that face the industry. To cope with many of these problems there has been enacted in recent years, state and federal legislation which has often resulted in marketing agreements. Here no attempt is made to determine the feasibility or success of the various pear marketing agreements that have been instituted. But in conjunction with additional information, the subsequent analyses and discussions may be helpful in evaluating some of them.

The wide scope of even such a limited subject as pear prices necessitates concentration, in a single study, on only a small segment of the whole. Hence, this investigation is limited to the behavior of auction

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⁴ Associate Agricultural Economist in the Experiment Station and Associate Agricultural Economist on the Giannini Foundation.

prices of California fresh Bartletts. Consideration is given to the supplies and prices of other pears and of certain other fresh fruits, however, to the extent that such study helps to explain the behavior of prices of California shipping Bartletts. Several aspects of fresh-pear prices discussed in an earlier general study of the pear industry⁵ will be considered here in more detail.

In several respects the prices of California Bartletts are a convenient medium for the study of fresh-fruit prices. The large bulk of fresh shipments is sold through highly organized auction markets in the large centers of population in the Middle West and the East. For a period of about twenty years, there are available daily auction sales and weighted-average daily auction prices from which may be constructed weighted-average prices for various time periods such as weeks, months, or seasons. In addition, federal and state marketing agreements have made available, for recent years, much detailed information, such as weighted-average prices of different sizes of fresh pears. Such diverse and carefully compiled series of prices serve as a reliable price record suitable for analysis and study.

Because of their perishability, California Bartletts cannot be stored over long periods. Since most shipping Bartletts are not stored at all but move into consumption immediately, there is no carryover of the fresh fruit from one season into another. In some respects, absence of carryover simplifies the problems in price analysis since the crop of one season does not directly influence the price of subsequent seasons. The alternative disposition of pears, however, into shipping, canning, and drying outlets complicates the analysis of fresh Bartlett auction prices because the volume of supplies entering into fresh shipments is a function of the prices and supplies of those canned and dried. The distribution of California Bartletts in various uses may be indicated by the following data. Out of the average annual harvested production of approximately 195,000 tons for the five years 1935-1939, about 35 per cent was canned and 18 per cent was dried.⁶ Bartletts have not yet been marketed in fresh frozen form, nor does this method of utilization appear likely in the near future. Of the 92,500 tons consumed annually in fresh form during 1935-1939, 71,000 tons were shipped out of the state. California Bartletts compete in consumption with other fresh fruits during the major part of the shipping season, and with the Pacific Northwest Bartletts during the last third of the shipping season. Thus the prices of California Bartletts are related to those of other pears and fruits.

⁵ Shear, S. W. Economic aspects of the pear industry. California Agr. Exp. Sta. Bul. 452:1-107. 1929. (Out of print.)

⁶ Shear, S. W. Deciduous fruit statistics as of January, 1940. Univ. of California Giannini Foundation Mimeo. Rept. 69:72. 1940.

RELATIONS BETWEEN WEEKLY AUCTION PRICES AND SALES

In the investigation of changes in time series of an economic nature, such as statistics on production and movement of supplies and prices, increasing attention is being given to the kinds of changes known as secular trends, cyclical waves, seasonal variations, and residual variations. A particular time series may be broken down into these four components which may be studied separately and in combination with each other. Secular trends and seasonal variations are often measured in order to eliminate their influence upon cyclical movements and thereby bring these movements into bolder relief. The study of secular trend and seasonal variation, however, is important for reasons other than the elucidation of cyclical movements. What have been viewed as residual variations may not be random in a probability sense, but the result of influences that have not been apparent until intensive study has been made of the economic and statistical relations involved. For some commodities, especially perishable ones, seasonal variation in the prices is of importance at least equal to cyclical and secular movements.

Unit-Time Intervals.—In the study of prices of a specific commodity, it is necessary to give some consideration to the appropriate time units to use. In certain analyses it may be essential to consider only annual prices; in others, monthly prices; in many, weekly prices; and in some, daily prices. The specific object of an investigation largely determines the unit-time intervals for the prices used. In the study of short-time price movements of a perishable commodity with a short marketing life, such as Bartlett pears, it is not only advantageous but also necessary to use prices of time units not longer than a week because available or potential supplies that influence price may change significantly within a period of several days or a week. Since the major part of the marketing season for Bartletts is about three months, monthly prices do not adequately reveal the short-run price movements within a season. The minimum time interval that discloses the important short-run price movements of California Bartletts is a week, and for some purposes the use of daily prices is helpful. In the analysis of seasonal variation in California fresh Bartlett auction sales and prices, weekly data have been used.

The problem of seasonal variation is of special importance in the study of perishable commodities such as fresh fruits and vegetables that are marketed and consumed in a relatively short interval of time. Perishability, that is, change in physical condition over time, largely determines the possibility of storage, and the length of time for which a commodity may be stored under ordinary conditions varies inversely

with its degree of perishability. The high perishability of some fresh fruits and vegetables necessitates their rapid marketing and immediate consumption. Although the relation between perishability, rate of marketing, and consumption is modified by elements such as cold storage, the degree of the relation and not its nature is affected. California fresh Bartletts are highly perishable, and only a few are held in cold storage, and then only for a few weeks, because the fruit deteriorates rapidly in quality and appearance even in cold storage. In addition, later Bartletts from other states and late varieties of pears compete with California Bartletts that have been stored, which introduces considerable speculative risk.

California Bartletts are grown in several different sections of the state,⁷ and the period during which they mature and are harvested is a relatively short one, usually about three months.⁸ Moreover, about four weeks after the first shipments from a particular district, the volume of movement from that district usually reaches a maximum. The rapidity with which California Bartletts are shipped from the state is due not only to the high degree of perishability of the fruit, but also to the fact that a large part of the fresh fruit is shipped in refrigerated cars over distances from 2,000 to 3,000 miles, requiring as much as 10 days en route to the larger midwestern and eastern markets. Substantial but considerably smaller amounts are also shipped under refrigeration in steamships to the east coast of the United States and to Europe. Interoceanic shipments from San Francisco to New York require about two weeks in transit, while steamship movement to Europe requires about three weeks for the 8,000-mile journey. The combination of perishability and distance from consuming centers, requiring rapid marketing and transportation under refrigeration, is not unique to California Bartletts, but common to all California fresh fruits that are so perishable that they can be stored safely for only a short time.

SEASONALITY IN AUCTION PRICES AND SALES

Construction of Average Prices.—Average weekly and season's auction prices are constructed from daily data published in the auction catalogs of the fruit auction companies. Before explaining the construction of a season's average price, it is necessary to emphasize that the

⁷ For location of pear-production areas in California, see the map in: Shear, S. W. Economic aspects of the pear industry. California Agr. Exp. Sta. Bul. 452:30. 1929. (Out of print.) Pear-production areas for the United States are shown on the map on page 11 of the same study.

⁸ For the state as a whole, the usual period of maturing and harvesting is about three months; for individual districts, the period varies from two and one half to three months. The period of maturing and harvesting in a single orchard, however, may be as short as two weeks. These estimates are based on examination of shipment data.

weekly prices are based on the daily prices. These daily prices are averages of the prices at which individual sales are made and are weighted by the respective volumes of sales. The weekly averages of daily prices are weighted by the daily volumes of sales; and the season's price, based on the weekly prices, is an average weighted by weekly volume of sales. Such weighted-average prices can be taken to be representative of the respective time periods such as a week or season.

The Auction Market.—Auction prices result from transactions in a market that, in character, closely approaches a perfectly competitive market. Samples of the merchandise designated according to grade and size are available for inspection before buying and selling begins, and no limitations are placed on entry, exit, or participation in the market. No one is obliged either to sell or to buy certain merchandise. The market is open to a sufficiently large number of buyers and sellers so that the entry or withdrawal of one buyer or seller does not significantly influence the price. One important exception to a perfectly competitive market pertains to the merchandise packaged with brand names. To this extent, product differentiation does exist in the minds of buyers and sellers.

Measurement of Seasonal Variation in Prices and Sales.—The date on which the California pear marketing season begins varies from year to year according to the time at which the fruit matures in the earliest producing districts, which in turn depends chiefly upon weather conditions and cultural practices. In constructing indexes of seasonal variation in the volume of sales and prices, the dates on which the different seasons begin must be considered, since all the seasons do not start on the same calendar dates. For the purposes of this study, the week chosen as the significantly initial one in each marketing season is the first week in which at least 2 per cent of the season's total sales in the New York market were sold. For example, in 1926 the first week in which at least 2 per cent of the season's total sales were made ended July 9; in 1927 the corresponding first week ended July 22; and in 1928 the first marketing week ended July 13. All of the first weeks, as thus determined, are considered together in computing the seasonal index of the first marketing week; and the subsequent weeks follow chronologically.

Figure 1 shows the indexes of seasonal variation in weekly sales and prices on the New York auction market by five-year periods during 1919–1938 for marketing weeks designated as 1 to 12 in table 13 (p. 298). The indexes of weekly volume of sales were constructed by first expressing the weekly sales of a given season as percentages of the average weekly sales of that season. From these percentages of all the like-numbered weeks was computed an arithmetic average which is considered as the index, or relative, of that week for a given period of years. In computing

the price indexes of a group of years, the average price of each week is expressed as a percentage of the season's weighted-average price, and an arithmetic average is taken of the relatives of the same numbered weeks of the years included in the group. An advantage of computing the indexes of seasonal variation in the sales and prices in this manner is that the secular and cyclical elements are sufficiently eliminated to place the corresponding weeks on comparable bases.

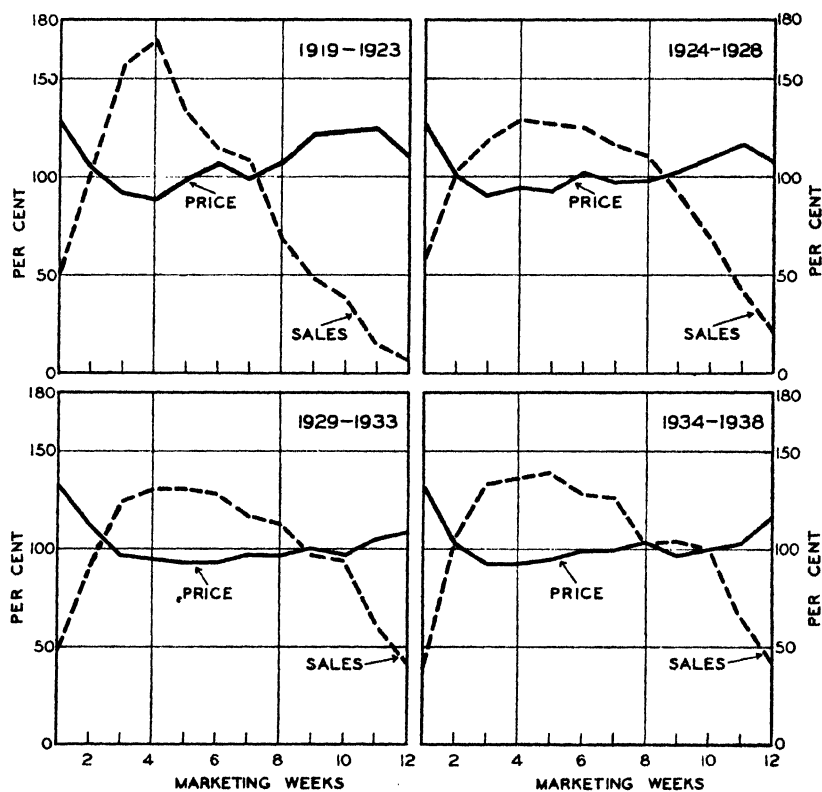


Fig. 1.—Relative weekly New York auction sales and prices of California Bartlett pears, five-year averages, 1919-1938. The marketing weeks of the individual seasons were determined by including those weeks having at least 2 per cent of the season's total.

Data from tables 14 and 15 (p. 301-2).

The very similar patterns of seasonal variation for the three periods from 1924 through 1938 (fig. 1) show an increase in sales from the first week of the season to a maximum in the fourth or fifth week, after which time the volume of weekly auction sales declines. The rate of increase in sales during the first four or five weeks is greater than the rate of decline in sales during the remainder of the season. Although the volume of

seasonal sales has followed such a general pattern during the past twenty years, a marked and important change in the conformation of the seasonal trend of sales has developed.

The seasonal variation in weekly auction prices follows a pattern which, in general conformation, is inverse to that of sales. The auction prices decline from the first week in the season to a minimum and then rise as the season progresses. However, the average maximum sales and minimum prices occurred in the same weeks, the fourth and fifth respectively, only in the two groups of years 1919-1923 and 1929-1933.

The general pattern of seasonal variation in sales is influenced by the perishability of fresh Bartlett pears. Moreover, the weekly movements of sales and prices are closely related. The causal connection between seasonal variation in the volume of sales and prices may be stated as follows: If the rate of consumption of a commodity is to be adjusted to the rate of output of that commodity, there must be a sufficient inducement for consumers to be willing to accept the output. The conventional explanation of such a concept is that as the quantity of good that is marketed is increased, its price per unit decreases in a certain proportion in order to induce consumers to take the increased output. Such an explanation is closely allied to and largely based on the demand-curve concept, where the demand curve does not shift position or change shape. With the demand and supply curves shifting in opposite directions or in the same direction but in different amounts the situation becomes complex, but more nearly approximates actual market conditions. The demand and supply curves probably change their shapes and positions from day to day according to changes in a large number of variables such as consumers' income, the volume and prices of other commodities, and anticipated future supplies and prices.

Although in general the seasonal variations in sales determine the seasonal variations in prices, at times the reverse may be true. In pears this may be illustrated by reference to the first few weeks of the season which are characterized by relatively high prices. These high prices encourage producers to place their fruit on the market in order to take advantage of the current price situation. At times this causes immature fruit to be shipped for sale before the expected seasonal decline in price occurs. In this sense the seasonal price pattern influences the seasonal sales pattern. This situation, however, is more striking during the latter half of the season. Pears that are ready for shipment during the middle of the season may be held back a short time in the expectation that higher market prices will prevail later. Thus the expected seasonal variation in prices to some extent may influence the distribution of shipments through the season.

The limited marketing life of Bartletts, together with the fact that an increasing quantity of pears becomes ready for market during the first to the fourth or fifth marketing week of the season, has caused the pattern of seasonal variations in shipments and sales to be largely independent of the seasonal variation in prices. Because California fresh Bartletts are so perishable and the opportunity for storage so limited, the resulting pattern of seasonal variations in the volume of sales or shipments is the chief factor determining the inverse pattern in seasonal variations of prices. Hence, the outcome of attempts to minimize wide

TABLE 1

COEFFICIENTS OF VARIATION OF WEEKLY SALES AND PRICES OF CALIFORNIA BARTLETT PEARS ON NEW YORK AUCTION, 1919-1938

Year	Sales	Prices	Year	Sales	Prices
	<i>per cent</i>	<i>per cent</i>		<i>per cent</i>	<i>per cent</i>
1919.....	55.7	12.4	1929.....	37.3	8.1
1920.....	63.1	12.5	1930.....	25.9	14.7
1921.....	70.3	19.4	1931.....	24.5	11.3
1922.....	41.9	17.1	1932.....	36.6	14.3
1923.....	56.0	13.0	1933.....	21.0	6.0
1924.....	37.3	5.5	1934.....	20.1	5.3
1925.....	44.7	17.2	1935.....	41.9	11.0
1926.....	30.9	13.3	1936.....	27.8	9.9
1927.....	36.1	14.1	1937.....	25.7	9.8
1928.....	23.6	14.3	1938.....	30.5	10.2

Source of data:

The coefficients are based on the data in table 13 (p. 298).

seasonal variations in prices of pears must depend largely upon the feasibility and success of minimizing wide seasonal fluctuations in the volume of Bartlett sales, since the flow of shipments is the only price-influencing factor, other than quality and size, that can be controlled to any extent by shippers.

Trend in Seasonal Variation.—The trend in the magnitude of seasonal fluctuations is shown in table 1. The coefficients of variation indicate the extent to which the relative variations in weekly sales and prices differ in the various years. In both the sales and prices, from year to year, there are wide fluctuations in the degree of variation; but nevertheless a definite downward trend in the amplitude is evident over the entire period since 1919. Examination of the data for individual years indicates that relative variations in the volume of weekly auction sales followed a sharply declining trend until about 1928, and thereafter flattened out and fluctuated about a horizontal trend. The relative variation in weekly auction prices also generally tended to decrease over the twenty-year period. The decrease before 1929, however, was substantially less than

the decrease in the relative variation in the volume of weekly sales for the corresponding years."

Comparison of Weekly Prices.—A graphical record of the weighted-average prices of all weeks and seasons from 1920 to 1940 is shown in figure 2. The horizontal dotted lines indicate average prices for the season and the fluctuations about the season's price represent the weekly prices; this clearly indicates the extent to which the weekly prices are represented by the season's weighted-average price. The figure also shows three important types of price movements—secular, cyclical, and seasonal—and it facilitates comparison of price patterns of the different years.

The weekly price record of California Bartlett pears illustrates the typical price behavior of a commodity characterized by the following elements: perishable and not physically adapted to storage over long periods; a marked seasonal variation in readiness for the market and hence in movement of supplies; rapid marketing over a period as short as three months; a semiluxury good to most and a luxury to many consumers; a nonstaple good that is relatively unimportant in diets; a good whose quantity of marketable supply, whose condition, and, to some extent, whose demand are dependent upon the variations of natural phenomena such as weather conditions.

Changes in the amplitude of fluctuations in weekly Bartlett prices are shown in figure 3 in a manner different from those in figures 1 and 2. The relative prices shown in figure 3 for weeks or groups of weeks are expressed as percentages of the weighted-average prices of the respective seasons. The top panel labeled "through week 2," shows for each year separately the percentage that the weighted-average price through the second week is of the corresponding weighted-average price for the whole season. With few exceptions the prices for early Bartletts have

* During recent years marketing agreements were set up partly to regulate the distribution of interstate shipments of California Bartletts throughout the season, and consequently might be expected to have influenced the seasonal patterns of auction sales and prices. Formal marketing agreements on interstate shipments of California Bartletts operated in 1935, 1936, 1937, and 1939, and during the 1934 season there was some voluntary shipper effort to restrict shipments during the weeks of maximum rate of movement. Although there was no formal marketing agreement in the 1938 season, through an informal agreement with the Agricultural Adjustment Administration and the Federal Surplus Commodities Corporation, a shipment holiday was put into effect for a short time. Reference to table 1 indicates that the two years previous to the agreements were characterized by seasonal variations smaller in relative magnitude than the years in which the agreements were in force. In the season of 1938, when there was no formal marketing agreement, seasonal fluctuations in the volume of sales were greater than in 1937, but less than in 1935 when there was an agreement. The magnitude of seasonal fluctuations in auction prices was practically the same in 1938 as in the three previous years when formal agreements were functioning; whereas in 1933 and 1934 seasonal variations were relatively less in magnitude than in any subsequent years, whether with or without marketing agreements.

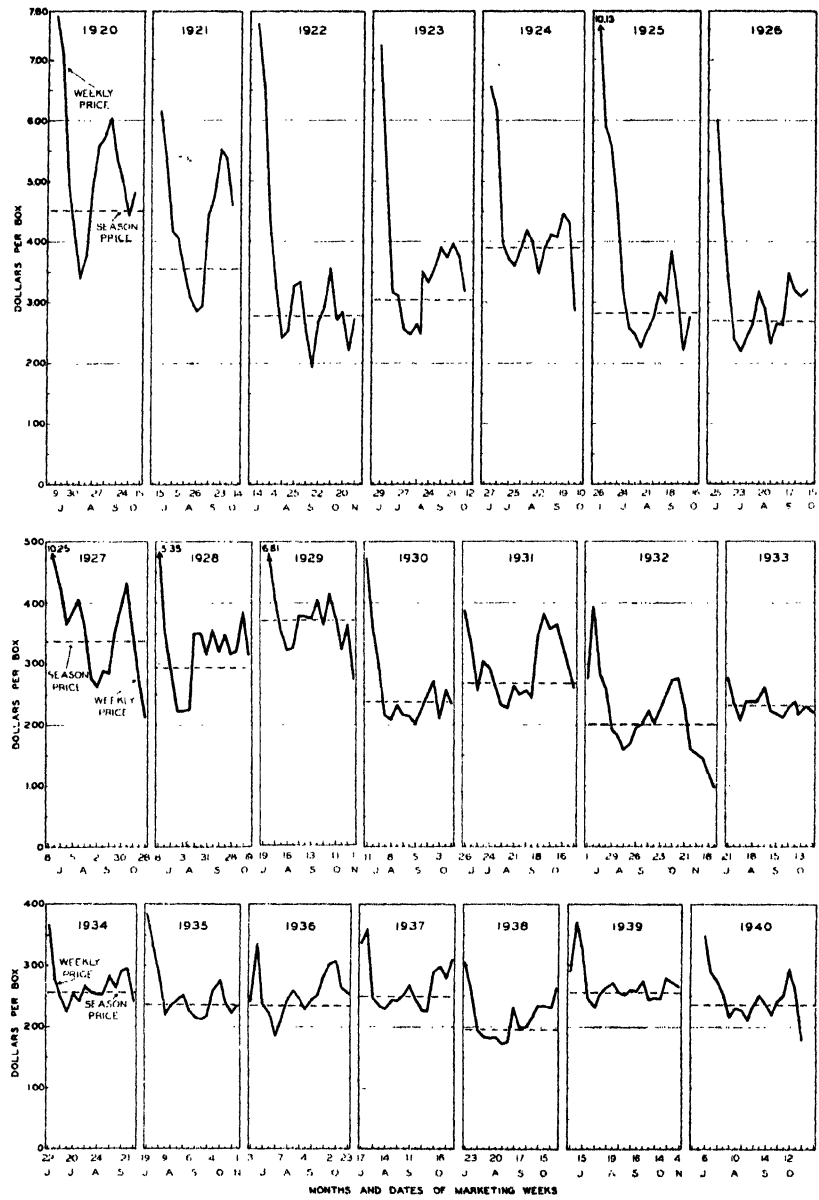


Fig. 2.—Weekly and season's average New York auction prices of California Bartlett pears, 1920-1940.
Data from table 13 (p. 298).

been noticeably higher than the season's average price, but there has been an appreciable decrease in the premium on them in recent years. Since 1930 there is noticeable a tendency for the average price through the

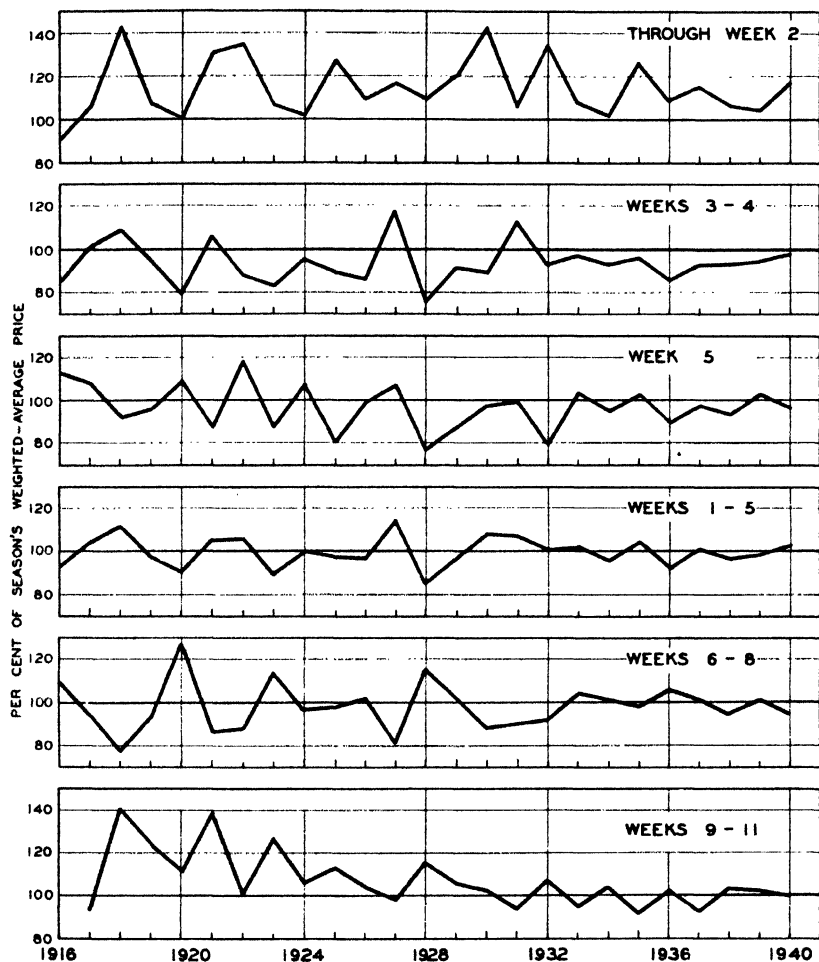


Fig. 3.—Relative weekly New York auction prices of California Bartlett pears by weeks and groups of weeks, 1916-1940.

Based on data in table 16 (p. 303).

second week of the season to be closer to the season's weighted-average price than was characteristic of earlier years. Prices during the third and fourth weeks (usually periods of heavy marketing) have generally been below the season's average, but since 1930 they have not been relatively as low as formerly.

The third panel in figure 3 shows that prices for the fifth week have tended to fluctuate around the season's average, but that since 1930 the relative deviations have been smaller than previously. Much the same tendency is characteristic of average prices through the fifth week except that they more nearly equal average prices for the whole season than do prices for any other period of weeks shown in figure 3. Prices for weeks six to eight have consistently tended to fluctuate around the season's average, with a noticeable decrease in amplitude since 1930. The greatest and perhaps most significant change in relative weekly prices, however, has occurred in late Bartletts. The bottom panel in figure 3 clearly shows that from 1918 to 1930 prices in weeks nine to eleven greatly decreased relative to season's weighted-average prices. After 1930 weekly prices of late Bartletts have closely approximated the season's weighted-average price.

Analysis of absolute deviations from season's prices, given in table 16 (p. 303), indicates tendencies similar to those shown in figure 3. The expression of weekly prices as percentages of season's prices has the merit of making the weekly price deviations of the separate years relatively comparable, since the season's prices vary from year to year, partly according to the general price level. Obviously, a deviation of \$0.10 from the season's weighted-average price of \$2.01 in 1932 is not comparable to a deviation of \$0.10 from the season's weighted-average price of \$4.51 in 1920. The relative data presented in figure 3 and the absolute data in table 16 both show that weekly price deviations from the season's prices have been substantially smaller since 1930 than in earlier years.¹⁰

Comparison of Weekly Sales.—The volumes of weekly auction sales as a percentage of the season's total sales for various weeks and groups of weeks are shown in figure 4. This figure shows that the season's sales have tended to be less concentrated in the first and second thirds of the season and more concentrated in the last third of the season, especially weeks nine to eleven. Furthermore, the variations in any given part of the season were much greater before 1925 than they have been since then. This smoothing of the relative distribution of sales through the season in recent years seems to be reflected in a somewhat corresponding decrease in relative variations in weekly prices (p. 240). In fact, the relations between weekly prices and sales substantiate the conclusions suggested earlier (p. 243) that the patterns of seasonal variation of weekly prices and sales have progressively changed so that since 1930 individual weeks of the season do not vary among themselves so much as during the 1920's.

¹⁰ This tendency does not appear to be a direct result of pear marketing agreements which were in force during the 1935, 1936, and 1937 seasons, since the tendency is apparent in earlier years and also in 1938 when there was no formal marketing agreement on Bartletts.

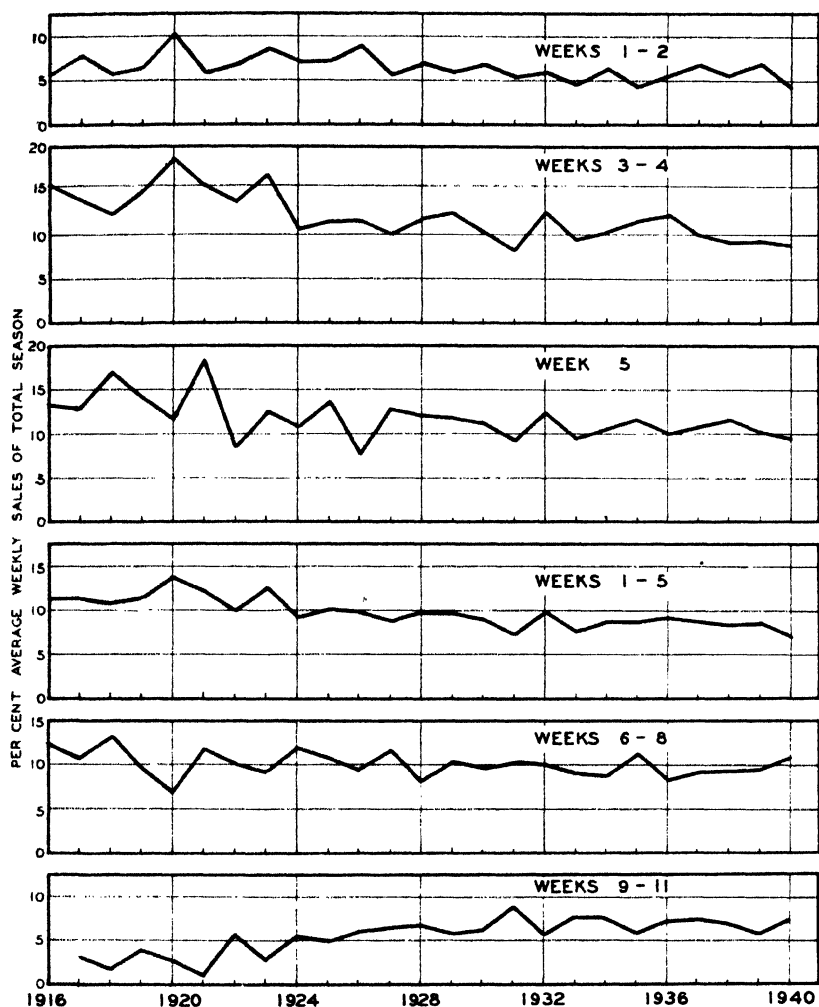


Fig. 4.—Relative weekly New York auction sales of California Bartlett pears by weeks and groups of weeks, 1916–1940.

Data from table 17 (p. 304).

Explanations of Change in Weekly Price Variation.—The question arises as to why the fluctuations in weekly prices have gradually decreased in relative amplitude of variation. This trend is largely due to a diminishing in the fluctuations of weekly auction sales associated with a smoother flow of shipments throughout the season. One may question why such a gradual change has occurred in the volume of weekly ship-

ments and sales. A change in the geographical distribution of the producing areas may be one explanation. The production of California Bartletts over a wider and more dispersed area has resulted in a shift in the relative importance of the early, midseason, and late Bartlett-producing districts of the state. The dovetailing and overlapping of shipping periods in the various districts may have resulted in a more even distribution of shipments and sales through the season. Another reason may be that through experience growers and shippers have learned to regulate their shipments more evenly through the season. There is less tendency to ship too early in the season, for experience may have taught that small, immature fruit not only is received unfavorably on the markets but also adversely affects the prices received for subsequent shipments. There is some evidence in this direction since auction sales in the earliest weeks of the season, that is, through the second week, are relatively smaller in volume since 1925 than they were earlier. The most significant shift in shipments and sales, however, is the large increase in the proportion moving during the latter part of the season, in the ninth through the eleventh weeks. The substantial premiums paid for late California Bartletts fifteen years ago undoubtedly were the major stimulus that led to a relatively great increase in the acreage, production, shipments, and sales of late California Bartletts. The greater use of cold-storage facilities is probably also partly responsible for the relative increase in auction sales of late California Bartletts. Furthermore, the increased production of Bartletts in the Pacific Northwest and of other varieties of pears on the Pacific Coast marketed when California late Bartletts are shipped also appears to be a factor partially responsible for the decline in the relative prices of California Bartletts sold during the last third of the season.

Systematic Variation in Weekly Prices and Sales.—In the discussion and analysis of seasonal variations in sales and prices, the rate of marketing California Bartletts has been pointed out (p. 241) as one of the influences determining the seasonal pattern in weekly auction sales and prices. In this connection it is also necessary to investigate whether the relations between auction sales and prices vary systematically from week to week. In order to place the correspondingly designated marketing weeks of the various years on approximately comparable levels, weekly relative sales and prices will again be used instead of the actual sales and prices. In the subsequent analysis, all of the designated first marketing weeks of the seasons 1924 to 1938 are considered together, all of the second weeks, and in a similar manner all of the following ten weeks. This will indicate the association between relative sales and prices in the various weeks as the season progresses. Furthermore, the degree of association between

the weekly sales and prices can be measured statistically, and the extent to which the twelve marketing weeks differ in a measurable degree can be determined.

Has there been some recognizable pattern indicative of changes in the degree of association between auction sales and prices as the season advances, for the period 1924-1938 as a whole? Table 2 gives some indications of the degree to which auction sales and prices have been associated in the twelve marketing weeks.

The correlation coefficients do not indicate that as the season progresses from week to week the degree of linear association between sales

TABLE 2
COEFFICIENTS OF CORRELATION BETWEEN RELATIVE WEEKLY SALES AND PRICES
OF CALIFORNIA BARTLETT PEARS ON THE NEW YORK AUCTION MARKET,
BY MARKETING WEEKS, 1924-1938

Marketing week	Correlation coefficient	Marketing week	Correlation coefficient
1.....	-0.36	7.....	-0.55*
2.....	-0.35	8.....	-0.67*
3.....	-0.62*	9.....	-0.34
4.....	-0.50	10.....	-0.62*
5.....	-0.41	11.....	-0.58*
6.....	-0.69*	12.....	-0.02

* The correlation coefficients designated by an asterisk exceed the 5 per cent level of statistical significance; the chances are less than 5 in 100 that correlation coefficients as high as those, or higher, would occur in a random sample from a population in which the two variables are not correlated. For thirteen degrees of freedom, $r = 0.51$ at the $P = 0.05$ level of significance.

Source of data:

Based on data in tables 14 and 15 (p. 301-2).

and prices changes according to some definite pattern. Both the fourth and fifth weeks are characterized by lower degrees of association than either the third or sixth week. The ninth week is characterized by a significantly smaller degree of association than either the eighth, tenth, or eleventh weeks. The highest degree of association between sales and prices apparently occurs in the sixth week, which in most seasons is after the week of maximum sales.

More significant than the correlation coefficients are the statistical measures referred to as regression coefficients. The regression coefficients between sales and prices, with the former considered as the independent variable, indicate the amount and direction of linear change in the auction price that accompanies a change of one unit in the auction sales. Table 3 lists such regression coefficients, one for each of the twelve marketing weeks of the season. Comparison of the computed weekly regression coefficients gives an indication of the extent to which the

price varies with changes in volume of sales in the different weeks.¹¹ As may be expected, the weekly auction sales and prices generally move in opposite directions. Furthermore, the relative amount of price change that accompanies a corresponding change in the volume of sales varies from week to week. But the price effect appears to be independent of the week of the season; the price effect of the first and third weeks is almost identical with that of the sixth and eighth weeks. The lack of significant association at the end of the shipping season may be chiefly due to the influences of the Pacific Northwest Bartletts and other pears that are then on the market in abundance.

TABLE 3
AVERAGE PERCENTAGE CHANGE IN PRICE PER BOX ASSOCIATED WITH A CHANGE
OF 1 PER CENT IN SALES, BY MARKETING WEEKS, 1924-1938

Marketing week	Regression coefficient	Marketing week	Regression coefficient
1.....	-0.38 ± 0.28*	7.....	-0.42 ± 0.18*
2.....	-0.23 ± 0.17	8.....	-0.39 ± 0.12
3.....	-0.38 ± 0.13	9.....	-0.28 ± 0.22
4.....	-0.33 ± 0.16	10.....	-0.28 ± 0.09
5.....	-0.23 ± 0.14	11.....	-0.26 ± 0.10
6.....	-0.37 ± 0.11	12.....	-0.01 ± 0.19

* Standard error.

Source of data:

Based on data in tables 14 and 15 (p. 301-2).

Table 3 gives some indication of the price sensitivity of the auction market in the various weeks of the season. There is some basis for judging the extent to which price changes are more sensitive to increases or decreases in sales in the various weeks. Again there is no definite pattern in the statistical measures and little statistical evidence that as the season progresses and as weekly sales increase to a maximum and then taper off, the weekly price changes that accompany a certain change in the sales follow a definite and consistent pattern. In other words, there is little basis for stating that in the weeks of the first half of the season a given relative increase in weekly sales would be accompanied by smaller or larger corresponding price change than in the weeks of the second half of the season. Thus, a variation in the volume of weekly sales in the first half of the marketing season appears to have no significantly different price effect than a variation in the volume of sales in the second half of the season. In fact, during the last week of the market-

¹¹ Since the prices and sales are expressed as percentages of season's weighted-average prices and season's average weekly sales, respectively, the regression coefficients measure the price change, in percentage points, that on the average accompany a change of 1 per cent in the volume of weekly auction sales.

ing season, changes in auction prices of California Bartletts are largely independent of changes in volume of auction sales.

PRICE RELATIONS BETWEEN SIZES

In the section "Seasonality in Auction Prices and Sales" weekly and annual weighted-average prices of all sizes of California fresh Bartlett pears have been considered. Here some attention is given to the prices of individual sizes. The price behavior of various sizes is described briefly, showing how, in certain years, prices of different sizes vary among themselves.

Season's Prices of Individual Sizes.—The extent to which season's weighted-average prices of all sizes include heterogeneous kinds of Bartlett pears is evident when the sales and prices of various sizes are examined. Pears are not an economically homogeneous commodity, and even California Bartletts are not strictly homogeneous with respect to quality and size. The diversity in size and quality is reflected in prices of the individual sizes. Weighted-average prices of all sizes, such as have been used in the foregoing pages, obscure the price relations between various sizes. Although such weighted-average prices are extremely useful and entirely adequate for many purposes, for some purposes the prices of individual sizes must be considered separately. Here, however, the discussion will go no further than to indicate briefly the extent of divergence between the prices of different sizes of California Bartletts sold on the New York auction market. The discussion between prices and sizes is necessarily limited to the recent seasons because data on sizes are not available before 1936.

Since various sizes of pears are approximately equally useful in satisfying consumers' wants, there are some grounds for expecting various sizes to compete with each other in sales on the auction markets. One might expect such intersize competition to result in a tendency for prices of the several sizes to bear some constant ratio to each other. The price per box of a certain size of California Bartletts may be influenced not only by the supply of that size but also by the supplies and prices of the various other sizes on the market. Very few purchasers insist on obtaining a particular size regardless of the relation of its price to those of other sizes. Certain sizes, however, may be preferred for home canning, and other sizes may be preferable for sale by the dozen on fruit stands. There are grounds for expecting that, in general, a high degree of competition prevails among the various sizes and that their prices are closely related.

Pear sizes are designated by the number of pears packed in a standard box. The usual range in the number of pears per box is from 60 to 210,

with the majority of the fruit falling in the sizes between 110 and 195 to the box. The individual sizes run as follows :

larger than 60's	100's	165's
60's	110's	180's
70's	120's	195's
80's	135's	210's
90's	150's	smaller than 210's

Between adjacent sizes the difference in pears per box is 10 from 60's to 110's and 15 from 110's to 210's. One can scarcely detect the difference between the pears in two adjacent sizes, such as 80's and 90's, but can easily detect it between those several sizes apart.

TABLE 4

SEASON'S WEIGHTED-AVERAGE PRICES AND SALES OF CALIFORNIA BARTLETT PEARS ON THE NEW YORK AUCTION MARKET, BY SIZES, 1936-1939

Size	1936		1937		1938		1939	
	Price per box	Sales	Price per box	Sales	Price per box	Sales	Price per box	Sales
	dollars	100 boxes	dollars	100 boxes	dollars	100 boxes	dollars	100 boxes
70's.....	2.29	5	2.38	15	2.06	1	2.25	1
80's.....	2.29	24	2.28	43	2.01	7	2.39	6
90's.....	2.29	57	2.25	98	2.05	25	2.46	22
100's.....	2.22	151	2.23	269	2.01	93	2.46	59
110's.....	2.21	239	2.24	370	1.93	174	2.49	105
120's.....	2.22	521	2.30	793	1.96	494	2.41	323
135's.....	2.30	1,361	2.39	1,723	1.99	1,228	2.48	902
150's.....	2.36	2,150	2.53	2,271	1.96	2,076	2.58	1,748
165's.....	2.36	2,256	2.63	1,791	1.96	2,384	2.60	1,927
180's.....	2.42	1,691	2.72	846	1.96	1,828	2.61	1,671

Source of data:

Based on data in tables 18 and 19 (p. 305-7).

Study of the prices of different sizes of California Bartletts reveals the great extent to which they are physically and economically heterogeneous. The price relations between various sizes resemble considerably the price relations between different commodities. One is impressed with the notion that in some instances it is necessary to consider individual sizes as special cases of a family—California Bartlett—which is only one variety of pears.

Table 4 gives season's average prices and sales of California Bartletts by sizes on the New York auction market for the four seasons 1936-1939. In 1936 every one of the sizes listed sold at a premium over the 110's. The premium ranged from only 1 cent a box for 100's and 120's to 21 cents for 180's. In the sizes which composed the large majority of sales—135's to 180's—the price per box tended to increase as the sizes decreased. The following year, 1937, was characterized by a similar pattern of relation between sizes and prices. The minimum price that season was for

100's and the premiums ranged from 1 cent for 110's to 49 cents for 180's. In 1937, prices per box of the sizes composing the majority of pears sold also tended to increase as the sizes decreased; this tendency was even more marked in 1937 than in the previous years. During 1936, and particularly during 1937, auction purchasers apparently preferred the smaller sizes of pears over the season as a whole. During the 1939 season smaller pears also generally were sold at a premium over the larger sizes, broadly similar to the price-size relations during 1936 and 1937.

In 1938 the relation between prices and sizes, however, was markedly different from that in 1936, 1937, and 1939. The larger sizes, 70's, 80's, 90's, and 100's, obtained a premium over the medium and smaller sizes. In fact, there were very small price differences in the sizes ranging from 120's to 180's. In 1938 auction-market buyers were not willing to pay premium prices for the medium and smaller California Bartletts. Table 4 indicates the divergencies in the sales and prices of various sizes of pears. No definite relation is apparent between the relative volumes of the different sizes and their prices. But the price differentials between sizes also reflect other varying influences such as firmness, maturity, and color. Thus, weighted-average season's prices of all sizes obscure the characteristics of the individual sizes as indexes of fruit prices obscure the price behavior of the index components.

Weekly Prices of Individual Sizes.—Price differentials between pear sizes are even more marked in weekly prices than in season's prices.¹² In the 1936 season, the smaller sizes, 150's, 165's, and 180's, sold at relatively low prices during the second and third weeks, apparently because of the relatively larger supplies of the smaller pears. But in the following weeks a change in the price-size relation is noticeable; the small sizes, 165's and 180's, sold at a slight premium over the medium. The general pattern of the fifth week resembles that of the fourth; but the smaller sizes enjoyed a greater premium over the medium and large. The price-size relations of the weeks seven to twelve, inclusive, largely resemble each other. A characteristic of the price-size relation is that as the season advanced small sizes were sold at a premium over medium sizes, which in turn received a premium over the large sizes. From the beginning to the end of the season the price-size pattern gradually changed, and in the last third of the season the relations between size and price were inverse to those during the first two weeks of the season.

The relations between weekly prices and sizes in 1937 closely followed the patterns of the previous year. The outstanding difference between the two years is that in 1937 smaller sizes were sold at a premium earlier

¹² Price and sales data by sizes for all the weeks in the four seasons 1936, 1937, 1938, 1939 are given in tables 18 and 19 (p. 305-7).

in the season than in 1936. But in both years there was a strong tendency after the season was well under way for the price per box gradually to increase as the pear size decreased. In 1938 the relation between size and price was different from that of 1936 and 1937. The smaller sizes were at a discount during the first half of the season, and subsequently sold at a premium over the medium sizes. But the larger sizes, 90's and 100's, also sold at a premium over the medium sizes in most weeks of the season. In 1938 there was no strong tendency in most weeks, as in 1936 and 1937, for the box price gradually to increase as the pear sizes decreased. During 1939 the price-size relations for individual weeks roughly corresponded to the relations in 1936 and 1937. Examination of the available data on the sales and prices of various sizes in the four seasons indicates only a tenuous and unreliable tendency for the price differentials between sizes to be determined by the relative volume of sales of those sizes. It is highly probable that varying qualities, of which there is no objective measure, are also instrumental in determining the price relations between sizes. But study of weekly price data on sizes indicates the extent to which weekly weighted-average prices of all sizes include what are in fact economically and physically non-homogeneous commodities.

Seasonal Variation in Prices of Particular Sizes.—Figure 5 shows the seasonal trends in the prices of three different sizes of pears for 1936 to 1939. The three sizes, 100's, 135's, and 180's, are shown for two reasons: first, they represent large, medium, and small pears, respectively; second, for sizes larger than 100's or smaller than 180's there are no continuous weekly prices. Examination of the seasonal trends in the weekly prices of the three sizes emphasizes certain relations between size and price discussed above (p. 251); in addition there is an indication of the extent to which the seasonal variations in the prices of the three sizes are similar in pattern. Figure 5 clearly shows that during the heavy marketing weeks of the 1936 and 1937 seasons the weekly prices varied inversely with the three sizes; the small pears, 180's, generally were sold at prices with a premium over the medium and large; the large pears, 100's, sold at prices with a discount under the medium and small. In the very early and late weeks of the 1936 and 1937 seasons, there was no consistent relation between size and weekly prices. In the 1938 and 1939 seasons small pears, 180's, did not consistently receive a premium. The marked relation between price and size that characterized the 1936 and 1937 seasons did not hold during the 1938 season. The patterns of seasonal variation in the weekly prices of the three sizes, 100's, 135's, and 180's, were broadly similar in conformation and resembled the pattern of seasonal variation in the weighted-average prices of all sizes.

At present it cannot be explained fully why in some years, as 1936 and 1937, small sizes consistently sold at a marked premium, and in another year, 1938, there was a marked change in the relation between size and price. Examination of the data on supplies of the various sizes does

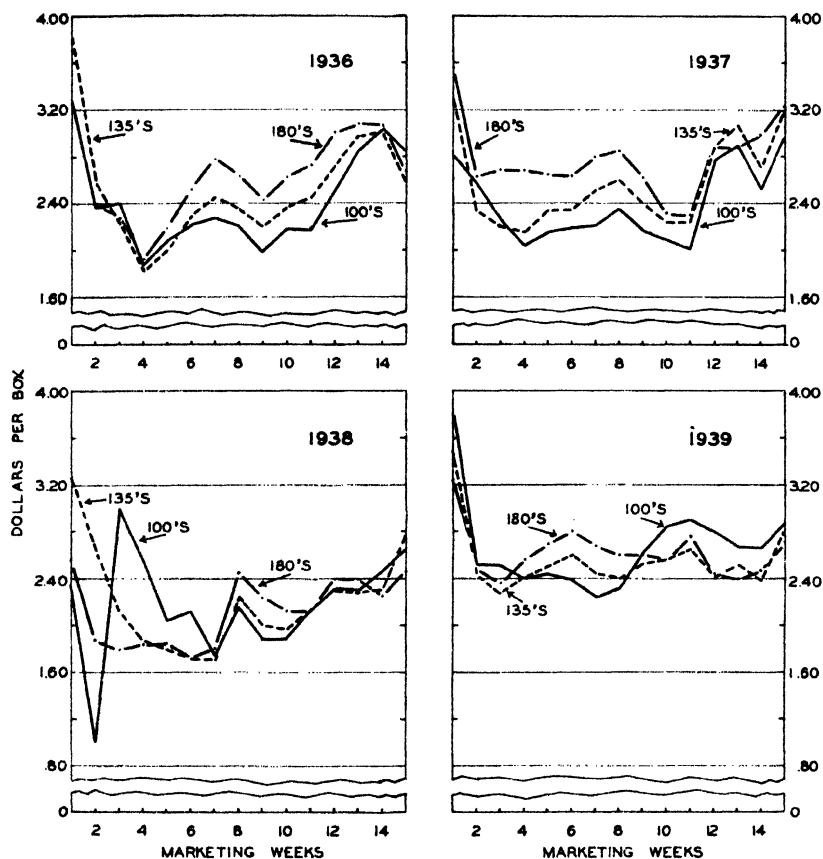


Fig. 5.—Weekly New York auction prices of California Bartlett pears by certain sizes, 1936–1939.

Data from table 18 (p. 305).

indicate that the prices of individual sizes are influenced in some degree by their supplies and those of other sizes. But relative volumes of supplies of various sizes do not wholly explain their relative prices. It may be that for various reasons consumers' preferences may change from certain sizes in one year to other sizes in another year. In addition, if there is some relation between size and quality, such relation may help to account for the relations between price and size. This complex relation between size, quality, and price is a subject that merits more study, but

the lack of adequate data on prices of various qualities of California Bartletts is a barrier to present extension of the analysis. At present only the extent to which prices of individual sizes differ among themselves can be indicated. Hereafter only the weighted-average prices of all sizes will be considered, since the relations to be discussed may be adequately examined by utilizing such prices.

The statistical data used in the preceding analyses pertain to the New York fruit auction market, the largest in the country. A presumption may be made that the relations between volume of sales, prices, and sizes in New York are also characteristic of other markets. But it is pertinent to investigate whether New York Bartlett prices are representative of those in other auction markets where substantial quantities of pears are sold.

PRICE RELATIONS BETWEEN AUCTION MARKETS

California Bartletts consumed in fresh form, except those used fresh in the state (about 12 per cent of harvested production during 1934-1938), are sold chiefly in auction and private markets in the Middle West and the East. The auction markets located in the large eastern cities receive the bulk of shipments, and the New York auction handles between 40 and 50 per cent of the total volume handled in all twelve auction markets. Largely because of the importance of New York as an outlet, New York auction prices are usually considered as representative of fresh-pear prices in general. In addition, New York prices are usually referred to since the most complete available records of Bartlett-pear prices are those pertaining to the New York fruit auction market. But the auction markets in other large centers of population and trade, such as Boston, Philadelphia, Chicago and Detroit, are important.

The data in table 5 indicate the extent to which New York dominates total auction-market sales. Since 1932 the relative importance of the New York auction has declined; whereas Philadelphia and Cincinnati, among other small markets, have increased their relative volume of sales. The distribution of sales among the various auction markets raises the question as to what extent New York prices are representative of those in other markets. In answering this question it is necessary to distinguish between different time units; weekly prices and season's prices must be considered separately.

SEASON'S AVERAGE PRICES IN MAJOR AUCTION MARKETS

Season's average prices in seven auction markets are available from the 1920 season to date. To compare the annual prices in different markets, the four markets selling the largest quantity of California Bart-

letts—New York, Chicago, Philadelphia, and Boston—will be used. The freight rate from California to the three Atlantic seaboard markets is \$1.63 per 100 pounds for a minimum carload weight of 27,500 pounds, but to Chicago the freight rate is \$1.63 per 100 pounds for a minimum carload of 26,000 pounds.¹³ The season's average prices in dollars per box in the four chief auction markets from 1920 through 1940 are given in table 20. The year-to-year changes in the prices in the four markets are similar in direction and approximately of the same amount. Such a

TABLE 5
DISTRIBUTION OF SALES OF CALIFORNIA BARTLETT PEARS
BY AUCTION MARKETS, 1932-1940

Auction market	1932	1933	1934	1935	1936	1937	1938	1939	1940
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
New York.....	47.6	48.1	46.7	47.9	43.0	40.0	43.6	41.2	39.2
Chicago.....	14.7	17.1	13.9	14.7	14.3	15.7	14.0	15.1	14.8
Boston.....	9.5	8.1	10.6	9.8	10.5	10.3	10.3	11.2	11.5
Philadelphia.....	9.2	9.5	11.4	10.8	11.2	10.6	11.0	11.6	11.2
Pittsburgh.....	3.0	2.5	3.2	2.7	3.5	4.0	3.1	2.6	3.8
Cleveland.....	2.8	2.6	2.3	2.5	3.2	4.1	3.2	3.4	4.2
Baltimore.....	2.2	2.3	2.7	2.4	2.5	3.2	2.7	3.7	3.5
St. Louis.....	2.0	2.1	1.8	1.4	2.0	2.3	2.4	2.1	2.2
Cincinnati.....	1.5	1.7	1.8	1.7	2.0	2.3	2.4	2.3	2.6
Minneapolis.....	2.7	2.4	0.8	1.9	2.3	2.5	2.8	2.8	2.7
St. Paul.....	1.8	1.1	1.6	1.2	1.7	1.6	1.8	1.8	1.5
Detroit.....	3.0	2.5	3.2	3.0	3.8	3.4	2.7	2.2	2.8
Total.....	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source of data:

Based on data in table 21 (p. 310).

relation is not unusual and may be expected from experience and from widely accepted price theory, since each market is highly competitive, and the trade in one market quickly becomes aware of the price situation in the other markets.

Relatively high prices in one auction market cause shippers to send a larger proportion of their shipments to that market. Conversely, relatively low prices in a market result in proportionately smaller shipments to that market. Consequently, the season's average prices in the various markets tend to approximate each other. But this tendency in Bartlett-pear prices is not evident if the prices are considered for periods of less than two or three months. Furthermore, differences in costs such as icing charges, and nonhomogeneity of goods in size and quality, tend to disequalize prices in the various markets.

¹³ Freight rates and refrigeration charges for shipments to each of the auction markets are given in table 24 (p. 314). By using the freight rate of \$1.63 per 100 pounds and a minimum-weight car of 27,500 pounds, the aggregate carriage cost (freight plus standard refrigeration) as of June 11, 1940, was \$0.988 per 50-pound box to New York, and \$0.959 to Chicago.

Examination of the season's average prices in the four markets leads to the observation that in all the years from 1920 to 1940, New York prices were either the highest or second highest in the group. In fact, New York prices were the highest of the group in all years except three; in 1922 and 1927 Chicago was highest; and in 1928 the Philadelphia price was higher than that of New York by only 1 cent. No one of the four markets consistently has the lowest season's average price, but in no year of the 1920-1940 period was it characteristic of the New York price to be the lowest.

The differentials between the Chicago annual prices and those of the three eastern auction markets do not consistently reflect the differentials in transport charges. For example, the Chicago price is not less than the New York price by the amount of the transport differential between the two markets. The excess of the New York price over the Chicago price varies from year to year and for two years the New York price was under that of Chicago. It may very well be that the price differentials between the markets in the various seasons may be accounted for largely by different sizes and qualities. Although since 1929 season's average prices in New York have been slightly higher than those in the other major auction markets, New York prices are perhaps more representative of pear prices than prices of other auction markets. This is largely due to the fact that New York is the largest auction market, and pear growers and shippers follow its prices closely.

The interaction between auction markets is related to shipments, car diversions, and telegraphic information sent from one market to another. Shipments are not directed to various auctions, according to some rigid rule, but on the basis of general and special information concerning demand situations, business conditions, and other information that may be available.

WEEKLY AVERAGE PRICES IN MAJOR AUCTION MARKETS

A number of important characteristics that are obscured in the season's averages become evident and are emphasized in the weekly prices. In the analysis of relations between weekly prices of various markets, eight of the twelve auction markets were considered. The choice of the individual markets was made on two criteria: (1) auction markets that are important on the basis of volume of sales; and (2) auction markets that are located in certain geographical areas. The two groups, four markets in each, were chosen as follows:

Group I	Group II
Boston	Detroit
New York	Cleveland
Philadelphia	Cincinnati
Baltimore	Pittsburgh

The markets in group I are all on the Atlantic seaboard and, except Baltimore, are of the larger markets. They are sufficiently close together so that there is no significant difference in carriage charges from California. The markets in group II are considered together since they are

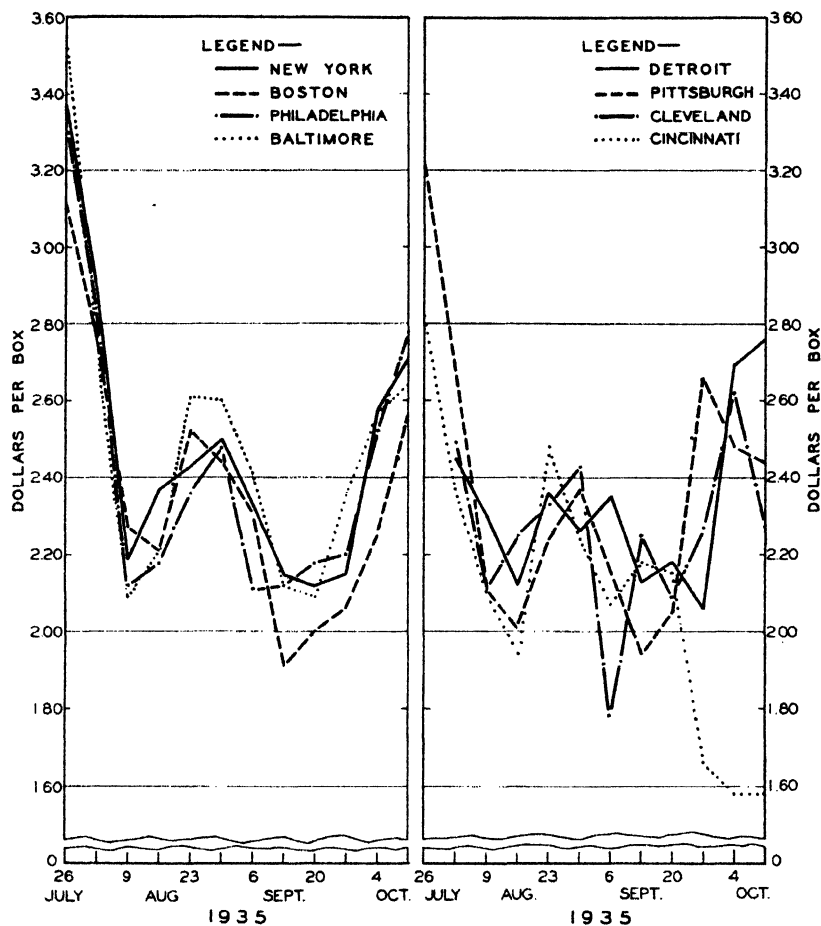


Fig. 6.—Weekly auction prices of California Bartlett pears in eight cities, 1935.

Data from table 22 (p. 311).

of approximately equal importance in sales volume and represent a fairly homogeneous group on the basis of transportation charges that are incurred in marketing California Bartletts. The latter are more comparable to each other in size than are those in group I. The weekly prices in the two groups of markets for 1935–1940, inclusive, are given in table 22; the prices for 1935 are shown in figure 6.

Seasonal Variation in Weekly Prices in Major Auction Markets.—The seasonal patterns of weekly prices in the six years 1935–1940 are broadly similar in each of the eight markets. The weekly price patterns, however, differ more than the season's prices discussed above (p. 255). Only in 1936 were the patterns of seasonal variation in weekly prices relatively close in conformation for both groups of markets. During 1935 the weekly prices of the eastern group of markets followed a broadly similar pattern, but in the more western markets the weekly prices were extremely divergent. Data for 1935–1940 are insufficient evidence from which to generalize that the weekly prices of one group of markets are more divergent than those of the other markets. There are no apparent *a priori* grounds for expecting eastern weekly prices to follow each other more closely than do those in the western markets. The differentials between weekly prices in the various markets are no doubt due to individual peculiarities in the several markets such as local situations in supply and demand of pears, different levels and distributions of money income, divergent qualities of particular receipts, and different situations in competition from other fruits and foods.

Among several auction markets the weekly prices may closely follow the prevailing price level or at times vary widely between themselves. The price differential from market to market may be only slight or sufficiently wide to indicate that special and unusual circumstances exist in some of the markets. When the price differences are small, they may be due largely to insignificant variations from the prevailing price level. But wide differences between the prices of auction markets cannot be dismissed as insignificant variations. There arises the problem of distinguishing price differences sufficiently wide so that they indicate unusual price relations between the several auction markets.

Clearly, the Bartlett price movement within a single season is dominated by the seasonal variation in price, which is largely due to the seasonal pattern of shipments and sales. There are statistical techniques useful in studying the extent to which prices in several markets, each one characterized by a marked seasonal variation in price, may exhibit chance variations from the prevailing price level.¹⁴ Such a statistical method, analysis of variance, is here used in studying the pear price relations between the auction markets in group I and in group II.

Analysis of Variance.—During 1936, 1937, and 1938, weekly prices in the two groups of auction markets did not widely differ among themselves, and the price differences may easily have been due to chance variations from the prevailing level of Bartlett prices. During 1935,

¹⁴ The technique is discussed in: Snedecor, G. W. *Calculation and interpretation of analysis of variance and covariance*. p. 21–28. Collegiate Press, Inc., Ames, Iowa. 1934.

however, the price behavior in both groups of auction markets was of a different character. In the 1935 California Bartlett-pear season, the differences between auction-market weekly prices were wider and more frequent than in the subsequent three years. The 1935 price differences between Boston, New York, Philadelphia, and Baltimore are barely significant. And in the same season price differences between the markets in group II—Detroit, Cleveland, Cincinnati, and Pittsburgh—were unusually wide and frequent. The latter price differences are sufficiently large so that they cannot be attributed to random variation of the auction-market prices from the prevailing level of Bartlett prices in the markets of group II.¹⁵

Large Differences between Weekly Prices of Auction Markets.—In examining the unusually wide differentials between the weekly prices of the markets in group II during 1935, the question arises whether an unusually large or an unusually small volume of sales was made in the markets whose prices were out of line with those of the other markets. As shown in figure 6, the price in Cleveland for the week of September 6 in the 1935 season was much below the price in the other markets. But the volume of sales in that week was only about three fourths of the average weekly sales in Cleveland during the season. On the assumption that the volume of sales is highly correlated with the market supplies,¹⁶ there is little evidence that the low price in Cleveland resulted from redundant supplies of Bartletts relative to other weeks in the season. During the week of September 6, 1935, Cleveland sales were 1.7 per cent of the total for the twelve auctions; whereas for the whole season, sales in Cleveland were 2.5 per cent of the total of the auction markets.

In the week ending September 27, 1935, there was a price spread of \$1.00 a box between Pittsburgh and Cincinnati. The relatively high price in Pittsburgh may be partly accounted for by its extremely small volume of sales during that week, but sales in Cincinnati were also very small. In fact, the Cincinnati price continued much below other market prices during the remaining two weeks of the marketing season. Detailed examination of the weekly data on sales and prices in the individual markets fails to give evidence that the auction-market price differentials are solely or even largely due to relative volumes of sales in the different markets. Extremely wide spreads between the weekly prices of different markets may result from numerous situations peculiar to individual markets. Some such situations may be due to market position of pears

¹⁵ The statistical results upon which these conclusions are based are given in table 23 (p. 313).

¹⁶ In the New York market, auction sales of Bartletts and supplies as measured by unloads of California pears, are highly correlated directly. This relation between auction sales and supplies in New York is the basis for the assumption that a similar relation is characteristic of the other markets.

other than California Bartletts; to the supplies and prices of other fruits; to the quality and size of Bartletts sold in the various markets. For many of these factors, such as the quality and sizes of weekly supplies in the individual auction markets, and the statistical position of competing fruits which may vary from market to market, adequate quantitative information is not available. Thus, the price differentials between auction markets can be explained only in general terms.

Factors Determining Prices in Various Auction Markets.—The factors primarily determining the prices in the various auction markets may be classified into two broad categories. First, there are those forces that are common to, and operate in, all of the markets. Such general influences dominate the wider price swings, especially those that occur over a period of several weeks or months. The pattern of seasonal variation in shipments and sales may be classified as such a broad general price influence. Forces in this category tend to maintain prices in a single market within certain limits of the prices in other markets, or what is usually referred to as "keeping the prices in line."

Second, there are those forces that are peculiar to individual markets. Such influences affect the daily and weekly price variations in single markets. The quality and sizes of shipments received in a market, the level of consumers' purchasing power relative to that in other markets, and the relative importance of other fruits are several of the many price influences that may be peculiar to a single market. Forces in this second category not only tend to cause price discrepancies between the various markets, but also prevent a prompt adjustment of such discrepancies.

The interaction of the two sets of price influences results in the inter-market price relations. Since season's average prices of the separate markets are primarily determined by influences common to all markets, they closely approximate each other. Daily and weekly prices in one market, however, often differ widely from corresponding prices in other markets because, over short intervals of time, such as several days or a week, the influences peculiar to a single market superimpose their price effects upon, and may even dominate, the price influences common to all markets. Consequently, within a single season there may be substantial price differences between several markets; but over the season as a whole the general price behavior in the several markets is similar and their season's average prices are close to each other.

In analyzing weekly price variability, variation within the two groups of markets has been considered. The analysis indicates that the broader price movements within the season are common to all auction markets, but over a period of several weeks prices in several markets may diverge widely. This was particularly true for the four western markets (group

II) during the 1935 season. Individual markets may reach their mid-season lows and peaks of prices in different weeks. Examination of price relations between various markets does not indicate that any particular market is dominant in price leadership; price movements in any particular market do not tend to follow the price movement initiated in some other market. The similarity of price movement common to all markets is not due to the influences operating in a single market, but is largely due to influences acting on all markets simultaneously. The fact that Bartletts are perishable and may not be easily arbitrated between markets as are many staple commodities, results in a certain degree of independence between the various pear markets. But a certain amount of diversion of cars is feasible. Fruit rolling east that was originally intended for New York may, on passing through Chicago, be diverted to Boston or Philadelphia. Pears once in New York are not likely to be shipped back to Chicago or St. Louis, but it is not unusual for an excess of cars on track in New York to be diverted to Philadelphia. Unquestionably, however, Bartletts are not diverted from one market to another to the same extent as less perishable agricultural commodities.

POLICIES OF DISTRIBUTING SHIPMENTS AMONG VARIOUS MARKETS

The price relations between auction markets are of considerable importance to growers, shippers, and sales organizations. The wide differences between auction-market prices frequently have been related, according to trade comments, to unsatisfactory distribution of shipments to the various markets. Trade papers frequently suggest that market gluts and associated relatively low prices are the results of overshipments to certain markets. These opinions have become so strongly entrenched that attempts have been made to distribute shipments "more evenly" between auction markets during the 1939 and 1940 seasons.

Marketing Policy of the Control Committee of the Deciduous Tree Fruit Marketing Agreement.—During the latter part of 1939 season and all of the 1940 season, the Control Committee of the Deciduous Tree Fruit Marketing Agreement operated on the premise that within a single season the weekly price differentials between markets are due largely to the manner in which pear shipments are distributed. Therefore, by the appropriate distribution of shipments between various markets the price differences could be influenced in such a manner that total net returns to growers would be increased. Shipment distribution was influenced by the following method. The Control Committee of the Deciduous Tree Fruit Marketing Agreement maintained a voluntary clearing-house whose function was to gather pertinent current information on the

flow of shipments and the supply and demand situation in the various markets.¹⁷ Each day the Control Committee issued a summary of the shipments and diversions to, and receipts in, the auction markets. Information on the volume of supplies due to arrive in the individual markets was also made available to shippers.¹⁸ Shippers having access to such information are in a more favorable position to direct and divert their shipments to those markets which they believe would yield the highest monetary returns. The supposed net effect or the purpose of such a program is to equalize, to a greater extent than previously, the prices in the different markets. In other words, the Control Committee attempted to approximate the same results that would be secured under a system of perfect competition.

The Control Committee did not set up a pooling system that would involve "the physical mingling of the products, the combining of sales returns, the merging of operating expenses, and the division of the net returns among the several members."¹⁹ On the contrary, each shipper was free to send his pears to whichever market he chose, and the sales returns went directly to him. Consequently, the Control Committee was not able to distribute shipments between markets so that aggregate returns to all growers would be maximized. Therefore, the Committee was not in a position to follow a policy of price discrimination between geographically different markets. Moreover, conditions other than supply control are necessary to make such a marketing policy feasible.

An Alternative Policy of Distribution of Shipments among Various Markets.—Very likely, the intermarket price differentials are partly due to the manner in which pear shipments are distributed between markets. Changes in the distribution of shipments may be expected to result in changes in the price relations between the auction markets. Under certain conditions, pear shipments may be distributed so that the prices in various markets will come closer together than they do under present methods of distribution. Such a goal in the distribution of shipments may be extremely difficult to attain, and especially to maintain. An alternative is to distribute shipments among auction markets so that their price differences will result in maximum returns to the group effecting the distribution.

¹⁷ Shippers were not obligated to give the Control Committee information on their shipments. All such information was given voluntarily, except data on daily total pack-out, which were required under the marketing agreement. The voluntary clearinghouse was largely a means of pooling and disseminating information of interest to shippers.

¹⁸ Information on eastern auction markets was first made available near the close of the 1939 shipping season. It was continued during the 1940 season.

¹⁹ Wellman, H. R., and M. D. Street. Maintenance of substantial equity in the pooling of lemons. California Agr. Exp. Sta. Bul. 619:1. 1938. This study concerns itself with many problems involved in the operation of pooling systems.

Under the assumption that growers as a group are interested in obtaining the largest returns possible from their pears shipped to the various markets, what conditions are necessary to obtain this ideal objective? First, all shippers must pool their shipments so that there will be a single control of supplies flowing to consuming centers. Under certain conditions, an industry having control over its supply may so regulate its distribution of output among several markets that its total net returns from all the markets will be a maximum.²⁰

Are the two conditions of market independence and different elasticities of demands²¹ in the various markets fulfilled by the major fruit auctions? There are grounds for believing that the pear auction markets cannot be divided so that they will be independent of each other. With price differences sufficiently wide to counterbalance transference charges, it is not only possible but logical for regular purchasers in one market to purchase their supplies in another market. If the Philadelphia price were sufficiently above the New York price, regular purchasers in Philadelphia would purchase their supplies in New York. This is what actually occurs at present, and is one of the elements that tends to keep in line the prices in the various markets. There is little doubt that the fruit auction markets are interdependent and cannot be divided at will. True, the Chicago and New York markets are less interdependent than are Philadelphia and Baltimore. Those who usually purchase their Cali-

²⁰ According to Mrs. Robinson (Robinson, Joan. *The economics of imperfect competition*, p. 179-202. The Macmillan Company, London, 1934.), the conditions are: (1) the markets are independent so that goods sold in one of the markets cannot be purchased there and resold in another market, and purchasers cannot shift from one market to another; (2) there is a difference between the elasticities of demands in the various markets in which the shipping organization sells its goods. If these two conditions are fulfilled, an organization that can control its output may regulate its sales in the various markets so that the marginal revenue received from selling an additional unit in any one of the markets is the same for all the markets in which it sells. When the marginal revenue in each market is equal to both the marginal cost and the marginal revenue of the entire output, the aggregate net returns will be at a maximum.

For total returns to be maximized rather than minimized, by equating marginal revenues in the various markets, the total-returns curves must meet certain conditions not adequately dealt with by Mrs. Robinson. Using for simplicity only two markets, the conditions may be indicated as follows: If both of the total-returns curves are concave from above, equating marginal revenues maximizes total returns. If both total-returns curves are convex, equating marginal revenues minimizes total returns. If the total-returns curve of one market is concave and that of the other market is convex, the result depends on which has the greater curvature. The curvature at any point may be mathematically expressed by the second derivative of the curve at that point. If the algebraic sum of the second derivatives of the two curves is positive, equating marginal revenues maximizes total returns. But if the sum of the second derivatives is negative, equating marginal revenues minimizes total returns from the two markets. For a detailed discussion of this and related problems see: Waugh, F. V., E. L. Burtis, and A. F. Wolf. *The controlled distribution of a crop among independent markets*. *Quar. Jour. Econ.* 51(1):1-41. November, 1936.

²¹ Elasticity of demand expresses a relation between changes in volume sold and changes in price; it is defined, at any price or volume of sales, as the proportional change of amount purchased in response to a small change in price, divided by the proportional change of price.

ifornia Bartletts on the Chicago market cannot shift to the New York auction as easily as a Baltimore purchaser can shift to Philadelphia. To this extent some degree of independence exists between the major fruit auction markets. But an element of considerable importance is the nature of perishability of California Bartletts. They cannot be transferred from market to market without unfavorably affecting their quality. Thus, the degree of market interdependence is sufficient so that shipments may not be regulated in one market without consideration to the effect on other markets.

But market independence is only one of the two conditions prerequisite to maximizing net returns by regulating shipments and influencing the market prices. The other condition is that in the separate markets the elasticities of demands are not equal. The functional relation between sales and prices should not be the same in all of the markets. Although the present writers are not in a position to maintain that the elasticity of demand for California Bartletts is substantially different in New York from that in Chicago, Philadelphia, or Boston, it may so be; only further analysis and study will give reliable indications.

The policy of geographical price discrimination by the Control Committee was not possible for several reasons. First, the Committee did not have the authority to pool shipments and control the flow of pears to individual markets.²² Thus, an essential condition of supply control was lacking. Second, the Committee did not have the authority to discriminate among shippers by directing the pears of one shipper to a market where the price is lower than in another market to which, at the same time, the pears of another shipper were sent. Individual shippers could not be expected to accept such a practice unless some equitable method of pooling sales returns were established. Third, a marked degree of geographical price discrimination would be hampered by the existence of fruits competing with California Bartletts in consumption. Relatively high Bartlett prices in some markets may result in consumers' turning to other fruits. Thus, it is fairly clear that geographical price discrimination is not a feasible method, under present trade conditions and at least under the voluntary clearinghouse, to increase growers' returns.

²² In a proposed marketing agreement regulating the shipping of fresh Bartlett pears grown in California, an interesting feature was that a committee would have the authority to regulate the distribution of shipments between markets. (See: Revised preliminary draft of a proposed marketing agreement regulating the shipping of fresh Bartlett pears, plums, peaches, apricots, and cherries grown in the state of California. Draft No. 2, January 3, 1939. Mimeo.) However, in the final agreement, the feature of intermarket regulation of shipments was not included. (See: United States Department of Agriculture Division of Marketing and Marketing Agreements. Marketing agreement regulating the handling of fresh Bartlett pears, plums, and Elberta peaches grown in the state of California. Marketing Agreement Series, Agreement No. 85:1-25. Issued May 24, 1939; effective May 29, 1939.)

One might question why a single shipper may not practice price discrimination in order to maximize his returns. The answer is that although a single shipper may control the distribution of his shipments to various markets, his supplies are such a small proportion of the total market supplies that he alone cannot substantially affect the market price. It is clearly to the advantage of each individual, acting alone, to send his pears to that market which at the time of his goods' arrival has the highest price and thereby receive as large net returns as he possibly can under the conditions. In fact, such a practice is one of the elements that tend to equalize prices in the various markets.

No doubt it is possible to improve the present methods of distributing Bartlett shipments among various markets. Improved channels of market information, more detailed knowledge of supplies and prices of other fruits that may compete with California Bartletts, and more detailed information on special circumstances in some of the markets are only several of many possible means of increasing the effectiveness in distributing Bartletts to the various auctions. Along such lines rather than following some rigid rule, improvements in market allocations are likely to result in increased net returns to growers and shippers. However, the fuller utilization by individual shippers of such information as noted above tends to equalize prices in the various markets, and yields results compatible with conditions approximating unrestricted competition.

RELATIONS BETWEEN PEARS AND OTHER FRESH FRUITS

In the study and analysis of California Bartlett prices it is at times convenient to disregard the prices of other fresh fruits and their relations to pears. But such a procedure can only be of temporary value, since California Bartlett pears are only one of a large number of fruits that receive consumers' attention in the market. Obviously, complex relations may exist between the various types of fruits and even varieties within one type. Therefore, some attention must be paid to at least several other fruits whose prices may be related to those of California Bartletts.

Bartletts from the Pacific Northwest (Washington and Oregon) are not shipped to the eastern markets until the last four or five weeks of the California shipping season. Consequently, during the first seven or eight weeks of their shipping season, California Bartletts are the only fresh pears available to consumers in substantial quantities. As for other fresh fruits, the situation is even more complicated. Considerable quantities of oranges, peaches, and plums are sold in the auction markets during the major part of the entire California Bartlett season. This consideration has led many connected with the California Bartlett trade to believe that

their goods suffer heavily from competition with other fresh fruits, especially oranges.

RELATIONS TO OTHER FRESH FRUITS

Trade journals frequently report that the "pear deal" has turned out unfavorably because fresh peaches or other fruits were abundant and cheap, or consumers are turning to citrus fruits. Not only are such comments numerous in fruit trade publications, but similar opinions are expressed verbally by some individuals in the trade. Examination of the literature on the demand and prices of fresh fruits, however, did not uncover economic and statistical studies giving evidence for concluding that pears do compete with other fresh fruits in consumption. For this reason, it was not only appropriate but also requisite that some attention be given to the relations of pears to the supplies and prices of certain other fruits.²³ Such information is not only useful but even necessary to evaluate adequately the effects of pear-marketing agreements and programs.

Concept of Related Demands.—Within the past two decades a considerable body of economic literature concerning related demands and competition among commodities has become available. Although such discussions have largely been theoretical and pertain to the principles involved, some of the literature concerns empirical tests of commodity competition, and such tests have been used in the study of relations between a number of agricultural goods.²⁴

In the statistical or empirical examination of the related demands of two goods, some objective criterion as a standard, or basis, is necessary. For instance, the term "competition" has already been used without stating in definite terms what is meant. True, the phrase "competing goods" connotes in some manner, even if a vague one, its meaning. It is also true that the words "competing goods" have what may be termed a "common-sense" connotation. But a disadvantage of not explicitly defining the conditions when goods may be considered as competing is that different individuals, or even the same individual at different times, may interpret the phrase in various senses.

Thus, in discussing the concept of related goods, it is useful for purposes of exposition to begin with two limiting cases: perfectly completing goods and perfectly competing goods. Two commodities may be defined as *perfectly completing* if they can be used only jointly and in a fixed ratio; they cannot be used separately. For example, a glove for

²³ For a critical summary discussion see: Hoos, Sidney. An investigation on complementarity relations between fresh fruits. Jour. Farm Econ. 23(2):421-33. May, 1941.

²⁴ Schultz, Henry. The theory and measurement of demand. p. 569-654. University of Chicago Press, Chicago. 1938.

the left hand and a glove for the right hand are perfectly completing for most people. Two commodities may be defined as *perfectly competing* if they can be substituted for each other in a constant ratio; one commodity may be substituted for the other, and each one can be used separately. Thus, assuming no difference in flavor, texture, color, and nutritive value, ketchup made from Maryland tomatoes and ketchup made from New Jersey tomatoes may be used as an example of perfectly competing goods.

Actually, however, very few, if any, pairs of commodities are perfectly competing or perfectly completing in consumption. But the implications that these two limiting cases lead to may serve as a basis for an empirical test of intermediate cases which are the most numerous and important in experience. The quantity and price data of perfectly competing and perfectly completing commodities would fulfill certain conditions. By using these conditions as criteria, an empirical test is suggested for ascertaining whether two commodities are competing or completing in consumption.

The conditions and test may be explained in the following terms: By definition, perfectly completing goods are consumed in a constant ratio to one another regardless of their relative prices. These conditions imply that for two completing commodities, even if they are not perfectly completing, their ratio of quantities consumed varies relatively less than their corresponding price ratios. By statistically measuring and comparing the relative fluctuations of the quantity ratios and price ratios, one has an objective basis for determining whether the two commodities are completing. Similar reasoning may be followed in testing whether two goods are competing in consumption. If two goods are perfect substitutes for each other, their prices must be in a constant ratio. Only one of the goods will be bought and consumed if their price ratio is different from that at which the two goods will be substituted for each other. By the definition of competing goods, their price ratio must be constant and equal to the same ratio in which one good can be substituted for the other. But regardless of their constant price ratio, the ratio in which the two goods are consumed is not restricted, and a relatively large change in the quantity ratio will result from a small change in the price ratio. The implication follows that for two competing goods, even if they are not perfectly competing, their price ratio varies relatively less than their quantity ratio. Thus by statistically measuring the relative variations in the ratios of prices and quantities, one may empirically determine whether two goods are competing in consumption.

To illustrate further, in investigating the related demands between pears and another fresh fruit, plums, data on supplies and prices are used over a sixteen-year period, 1924-1939. Over such a period two goods

may be competing in one part of the period and noncompeting in another part. Furthermore, the two goods may be competing within one range of prices and noncompeting in another range. But in considering the period as a whole, the statistical results do not apply to individual years, or indicate to what extent the relations between the commodities are changing over time. The results are indicative of average relations over the sixteen-year interval, though study of agricultural commodities familiarizes one with the fact that to some extent each season has its individual characteristics and is a new experiment.

As noted above, quantity and price data are utilized in empirically determining the related demands of pairs of goods. But consideration must be given to the time units of the data. For example, in studying the relation between Bartlett pears and oranges during November, the results probably would be different from those for the period from July to September. In the July–September period, there is heavy marketing of pears and very small marketing in November, whereas the marketing of oranges during the two periods has less of a seasonal variation. Furthermore, the relations between pairs of goods may change over time. Changes in consumer choices and food habits, and technological and sociological developments are reflected in variations in the relations between many commodities. Hence, the correlated demands of various commodities should not be considered any more permanent than the state of technological development, consumers' wants and opinions, and the level of economic development.

RELATIONS OF THREE OTHER FRESH FRUITS TO PEARS

Three other fresh fruits—peaches, plums, and oranges—have been selected to compare their relations with pears. The price data of the four fruits are averages for sales in New York for the two-month period of July and August. The quantity data refer to unloads in New York during the same two-month interval. The period July and August was chosen because heavy marketings of pears, peaches, plums, and summer oranges take place during those months. The pear, peach, and plum seasons do not entirely coincide; thus it is necessary to study the intercommodity relations during a period when relatively heavy unloads are made in all the fruits considered; July–August is such a period.

Trends in Unloads and Prices.—As shown in figure 7, from 1924 to 1939 the tonnage of July–August orange unloads in New York fluctuated about a strongly rising trend. The large increase is a rough index of the growth in the consumption of citrus fruits. Average annual July–August unloads for 1934–1939 were about 60 per cent larger than those during 1929–1933; but during 1934–1939, orange unloads averaged only

slightly higher than the immediately preceding years. From 1924 to 1931 peach unloads during July–August fluctuated widely about the level of 40,000 tons, with 30,000 tons in 1930 and 50,000 tons in 1931 as the extreme variations. Since 1932 the volume of peach unloads has fluctuated

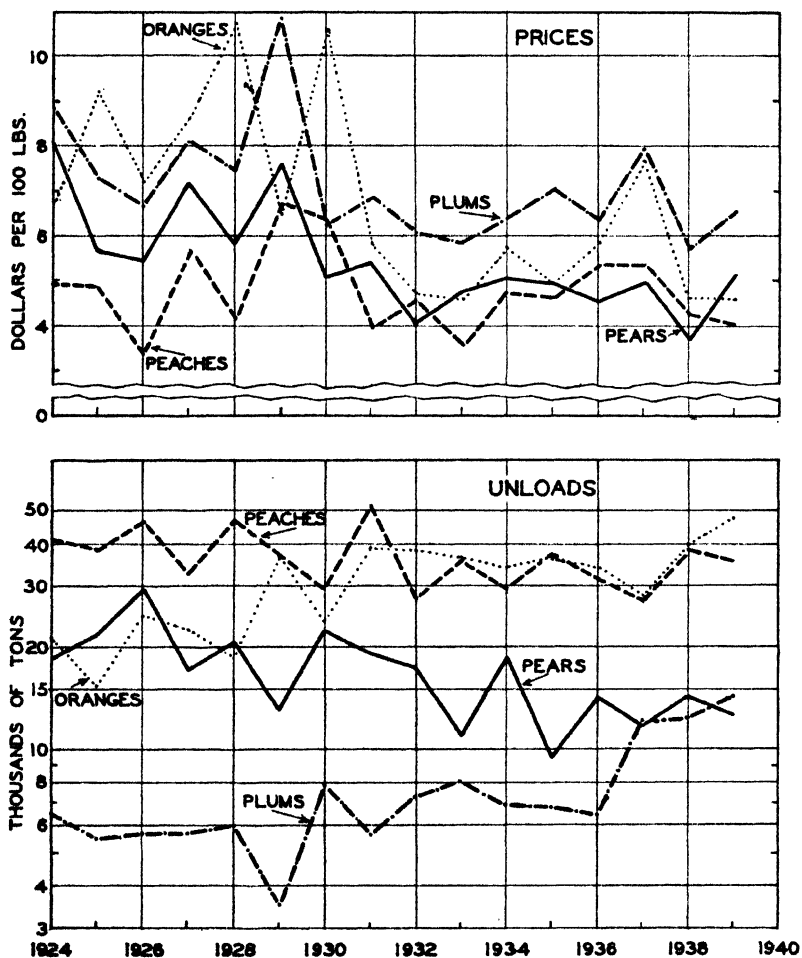


Fig. 7.—New York wholesale prices and unloads of pears, plums, peaches, and oranges, July–August, 1924–1939.

Data from tables 25 and 26 (p. 315 and 316).

relatively less widely and followed a lower horizontal trend. Over the 1924–1939 period as a whole, peach unloads have followed a slightly declining secular trend. Since 1935 the July–August unloads of oranges and peaches have been about equal when measured in number of tons.

Unloads of plums followed an upward trend from 1924 to 1933, declined during the next three years, but in 1937 and 1938 were double the 1924–1928 average with unloads of about 12,000 tons. The secular trend in unloads of plums has been markedly upward.

Although California Bartlett unloads for July and August have varied greatly from year to year during 1924–1939, the secular trend has been definitely downward. Such a trend is particularly evident when contrasted with the rising trend in the unloads of plums and oranges. Figure 7 shows that average unloads of pears and oranges were about the same during 1924–1928, but by 1935–1939 unloads of oranges had increased until they were over two and a half times the unloads of pears during the same period. Unloads of pears, which were about four times the volume of plum unloads during 1924–1928, declined to about one and a half times the plum unloads for the period 1935–1939, and during 1938–1939 were about equal to plum unloads. These broad comparisons indicate that per-capita consumption of pears in July and August, at least in New York, declined not only absolutely but also in relation to plums, peaches, and oranges during the sixteen-year period from 1924 to 1939.

The prices of the four fruits—pears, peaches, plums, and oranges—shown in the upper deck of figure 7, are expressed in terms of dollars per 100 pounds in order to compare the prices relative to a common base. A shortcoming of the procedure used here is that 100 pounds of one fruit, oranges for example, may have a different nutritive value than 100 pounds of pears. One method of overcoming this disadvantage is to express the prices of the various fruits in terms of a measure of nutrition, such as a certain number of monetary units per 1,000 calories. But from a dietetic and even an economic basis, nutritive value is not the only consideration in price comparisons; consumers' preferences and tastes, regardless of relative nutritive values, also are important elements. For these reasons the conventional method of expressing the prices in terms of a common unit of weight has been followed.

The upper deck of figure 7 shows the July–August prices of the four fruits at New York from 1924 to 1939. No two of the price series are perfectly correlated, but certain characteristics are common to all of them. In general, the four price series followed a rising trend to 1929, and after 1930 were at a lower level. Over the sixteen-year period, the pattern of California Bartlett prices followed the pattern of plum prices more closely than that of the other two fruits. The year-to-year changes in the prices of pears and plums parallel each other very closely during most of the period. This price relation indicates that probably pears and plums are competing in consumption.

An important feature emphasized by figure 7 is the relative position of pear prices in comparison with the prices of the other three fresh fruits. Pear prices reached their depression low point in 1932, and since then have recovered relatively less than the prices of the other fruits. Prices of peaches, oranges, and plums were at their depression low points in 1933, and by 1937 had recovered considerably. Plum prices appear to have suffered the least from the impact of the 1930-1935 depression. The failure of a more marked recovery in pear prices since 1932 is important because unloads and sales have generally been decreasing from 1926; consequently, gross returns to growers and shippers have declined. Thus, the question arises whether the decreased sales and low prices of California Bartletts may have been due directly to competition from other fruits. In attempting to answer this question, it is necessary first to obtain objective evidence whether pears do compete in consumption with plums, peaches, and oranges.

STATISTICAL TESTS TO DETERMINE DEMAND RELATIONS BETWEEN PEARS AND THREE OTHER FRUITS

In order to determine the relations in consumption between pears and the three other fruits, certain statistical tests were used.²⁵ The results of the tests apply to large groups of people and not to particular individuals. According to certain criteria of competing and completing goods, it may be shown that two goods, for example butter and margarine, are competing in consumption. Such a result is an average relation and probably does not pertain to some individuals who might not consider buying and consuming one of the goods under any conditions. Some individuals may dislike or be allergic to a certain food, in which special case that food does not compete with other commodities in the consumption of that particular individual. But that is an unusual situation which may not be characteristic of large groups of people. One must bear in mind the distinction between characteristics of individuals and characteristics of groups of individuals. It is the latter which are of interest here from the standpoint of relations between pears and other fruits.

Before applying statistical tests²⁶ to determine the relations between California Bartletts and certain other fresh fruits, it is important to emphasize that the results obtained by any statistical test are not decisive.

²⁵ For a discussion of the use and interpretation of the statistical tests of related demands see: Hoos, Sidney. An investigation on complementarity relations between fresh fruits. *Jour. Farm Econ.* 23(2):421-33. May, 1941.

Kozlik, Adolph. An investigation on complementarity relations between fresh fruits: A reply. *Jour. Farm Econ.* 23(2):654-56. August, 1941. This second article discusses the inadequacy of the type of analysis given below under test 1.

²⁶ In the text discussion, two tests and their results are noted. In Appendixes A and B these tests are discussed in further detail, and two additional tests are examined.

The most one should expect from such tests is empirical evidence that must be judged on the basis of experience, knowledge of the commodities concerned, and other pertinent information. Regardless of the shortcomings of such tests, however, they are helpful in studying and analyzing the relations between various commodities.

Test 1.—The first test of related demands compares the relative variation in the price ratios and quantity ratios of two fruits. The reasoning behind this test is outlined above (p. 267). Coefficients of variation are used in determining the relative variation in the price ratios and quantity ratios. The results of this test are given in table 6. These results indicate

TABLE 6
VARIATION IN PRICE AND QUANTITY RATIOS OF PAIRS OF FRUITS

Commodities	Coefficients of variation* and their standard errors		Apparent type of relation
	Price ratios	Quantity ratios	
	<i>per cent</i>	<i>per cent</i>	
Pears and plums.....	7.3 ± 1.3	28.7 ± 5.6	Competing
Pears and peaches.....	17.0 ± 3.2	26.0 ± 5.0	Competing
Pears and oranges.....	27.1 ± 5.3	32.6 ± 6.6	Noncompeting?

* Before computing the coefficients of variation, the quantity ratios and price ratios were adjusted for trends, the equations of which are given in Appendix A (p. 292).

Source of data:

Based on data in tables 25 and 26 (p. 315 and 316).

some important and interesting relations between California Bartlett pears and the other three fruits. If the presumption is that the degree of competition varies directly with the extent to which the variation in the quantity ratios is greater than the variation in the price ratios, then pears compete more strongly with plums than with peaches. Pears and peaches do compete in consumption according to the above test, but to a lesser degree than might be inferred from statements made by numerous individuals connected with the fruit trade. Moreover, the opinion that pears suffer most from competition with peaches is not supported by the above analysis.

The relation between pears and oranges is ambiguous, at least on the basis of the preceding test. The coefficient of variation of the quantity ratios is larger than the coefficient of variation of the price ratios, and this relation suggests that pears and oranges are competing in consumption. But the difference between the two coefficients of variation appears not to be sufficiently large to be statistically significant. The probability that the difference between the two coefficients may have been due solely to chance may be sufficiently large so that it is doubtful whether the two

goods are competing.²⁷ Although the above test does not give a criterion for independent goods, the presumption is that when the difference between the two coefficients is not statistically significant the two goods may be regarded as independent. Such reasoning suggests that pears and oranges may be independent in consumption rather than directly competitive, although such a conclusion is not in accordance with the opinions of many in the pear trade.

TABLE 7

THEORETICAL AND OBSERVED CONDITIONS ON THE DEMAND FUNCTIONS AS CALCULATED FROM THE ARITHMETIC DEMAND EQUATIONS FOR PEARS, PLUMS, PEACHES, AND ORANGES IN NEW YORK CITY, JULY-AUGUST, 1924-1938*

(Figures in parentheses are standard errors)

Commodities	Hotelling condition†		Probable type of relation
	$\frac{\partial y_i}{\partial z_i}$	$= \frac{\partial y_j}{\partial z_i}$	
Pears and plums.....	-0.00657 (0.00928)	$\approx$ -0.01976 (0.00530)	Competing
Pears and peaches.....	-0.00021 (0.00255)	$\approx$ -0.00690 (0.00388)	Competing
Pears and oranges.....	+0.00293 (0.00307)	$\approx$ +0.00551 (0.00686)	Completing

* The observed conditions are taken from the multiple-regression equations given in Appendix B (p. 294).

† In mathematical terms, the Hotelling condition may be expressed as follows: The partial derivative of the price of A with respect to the quantity of B equals the partial derivative of the price of B with respect to the quantity of A; or $\frac{\partial y_a}{\partial z_b} = \frac{\partial y_b}{\partial z_a}$. An alternative expression of the Hotelling condition is $\frac{\partial z_a}{\partial y_b} = \frac{\partial z_b}{\partial y_a}$.

‡ z_i, z_j = quantities demanded of any two commodities, unloads in 100 tons. y_i, y_j = the corresponding prices, dollars per 100 pounds.

Test 2.—The second test of related demands is more directly related to the theory of demand. The statistical results are shown here together with a brief discussion of the test to which Schultz refers as the "Hotelling condition" of "the special theory of related demands."²⁸ Table 7 shows the results of test 2 (for further detail see Appendix B, p. 293-96). According to the Hotelling condition, if two goods, A and B, are related in consumption and consumers act rationally, the change in the price of A brought about by a change in the quantity of B equals the change in

²⁷ The conventional interpretation of standard errors computed from time-series data cannot be relied upon, since the necessary sampling conditions are not fulfilled by time-series data used here. But the difference between the coefficients of variation of pears and oranges is so small in comparison with the coefficients themselves that it is highly suggestive that the difference is statistically insignificant. In contrast, the differences between the coefficients of variation of the other two pairs of fruits are sufficiently large in relation to the coefficients themselves that it appears highly probable that pears compete with plums and peaches in consumption.

²⁸ Schultz, Henry. The theory and measurement of demand. p. 569-604. University of Chicago Press, Chicago. 1938.

the price of B brought about by a change in the quantity of A. If the two goods are competing, the quantities change in the opposite direction of the prices of the related goods; and if the goods are completing, the quantities change in the same direction as the prices of the related goods.

Examination of table 7 indicates that for two pairs of goods—pears and plums, and pears and peaches—both terms of the Hotelling-condition equation are negative; whereas for pears and oranges both terms of the equation are positive. Since the signs are alike in both terms of each of the equations, the Hotelling condition is verified qualitatively. The test suggests that pears are competing with both plums and peaches, but completing with oranges. These conclusions follow if the signs of the terms in the Hotelling-condition equations are viewed as the criterion of classification as competing or completing goods.²⁹

When one recalls that competing goods may be substituted for each other, the empirical results of tests 1 and 2 appear logical. Pears, peaches, and plums are deciduous fruits that may be eaten fresh or preserved. But oranges, a citrus fruit, are usually purchased and utilized to meet a want different from that which pears usually satisfy. A large proportion of the oranges purchased are consumed in the form of juice.³⁰ To that extent pears and oranges are not highly substituted for each other in consumption. Consequently, the results of the two tests agree with what one might expect from the nature of the commodities and their conventional use. Furthermore, the results agree with the opinions of a number of fruit retailers questioned by one of the writers.

RELATED DEMANDS AND FORMULATING MARKETING POLICIES

The apparent fact that pears compete with plums and peaches in consumption may be of considerable importance in the formulation of marketing and price policies by grower and shipping interests and other groups in the pear trade. If pears compete in consumption with plums and peaches, there are grounds for expecting that when large supplies of plums or peaches are on the market so that their prices are depressed, the price of pears will also decline, since consumers may substitute plums or peaches for pears. But relatively short supplies of plums or peaches are likely to be associated with increased prices of the two fruits, and

²⁹ The criterion that both terms of the Hotelling-condition equation have the same signs is more liberal than the dual requirement that in addition to having the same signs, the two terms must be equal, or at least approximately so. Even with this liberal criterion, the conclusions regarding pears and the other three fruits may be statistically invalid since in each of the equations at least one term is smaller than its standard error.

³⁰ The extent to which oranges are consumed in the form of juice is indicated by an estimate of the California Fruit Growers Exchange in 1937 that approximately two thirds of the annual orange crop is consumed in the form of juice. (California Fruit Growers Exchange, Annual Report 1937:24. 1937.)

consumers may substitute pears for plums or peaches. Consequently, the market demand for pears may increase and result in an increased price for pears. On the grounds that pears and oranges do not compete in consumption, which the preceding analyses indicate, large supplies and low prices of oranges do not directly adversely affect the prices of pears. The existence of related or correlated demands between various commodities may considerably affect the outcome of a marketing agreement pertaining to only one of the commodities.

Since 1933 various forms of marketing agreements on California Bartletts, under state or federal jurisdiction, or both, have been in effect. Some of those agreements contain features designed to enhance growers' returns by regulating the flow of shipments and raising the market prices. But under certain conditions the net effect of such agreements may be undesirable from the viewpoint of pear growers. A price-raising, pear-marketing policy, formulated without reference to the correlated demands between pears and peaches or pears and plums, may result in consumers' substituting plums and peaches for pears to such an extent that the returns to growers may actually be reduced. A brief for or against marketing agreements is not presented here, since their feasibility and success depend on many additional considerations other than related demands. But it is suggested that in the discussion, formulation, and prosecution of marketing programs, consideration be given to the relations between various commodities.

Although the relations of pears to only three fruits—plums, peaches, and oranges—have been considered, it should not be inferred that pears are not related in consumption with other fruits. In fact, it is likely that each fruit (even each food product) is surrounded by a number of related commodities, some competing, others completing, and still others that are independent in consumption. An adequate examination of the interrelations between the many different fruits is a subject that will require much additional theoretical and empirical investigation. This section of the present study must be viewed only as a modest beginning in that direction.

ANALYSIS OF SEASON'S AVERAGE PRICES

This section is concerned with isolating and measuring the influences that have largely accounted for the year-to-year fluctuations in the season's average prices of California Bartletts. An attempt is made to answer the question: What have been the chief factors that have determined the season's average prices of California fresh Bartletts in eastern auction markets during the 1925–1940 period, and what have been the separate or partial influences of those factors?

The following analysis indicates that the major influences which have, on the average, primarily determined the season's weighted-average delivered-auction price of California fresh Bartletts in the seven chief markets during the 1925-1940 period were as follows: (1) volume of interstate shipments of all California pears during the California Bartlett shipping season, (2) volume of Oregon and Washington shipments of pears during the California Bartlett shipping season, (3) the level of United States nonagricultural income payments for July through October, and (4) a "time" trend which represents those factors that have

TABLE 8

UNITED STATES ANNUAL PER-CAPITA CONSUMPTION OF PEARS, 1924-1938

Use	1924-1928	1929-1933	1934-1938
	<i>pounds, fresh equivalent</i>	<i>pounds, fresh equivalent</i>	<i>pounds, fresh equivalent</i>
Fresh.....	6.6	6.0	7.1
Canned.....	0.7	1.0	1.3
Dried.....	0.1	0.1	0.1
Total.....	7.4	7.1	8.5

Source of data:

From: Shear, S. W. *Deciduous fruit statistics as of January, 1941*, Univ. of California
Giannini Foundation Mimeo. Rept. 76:4-6. 1941.

linearly and smoothly changed through time. Influences other than the four listed above, however, have been instrumental in determining Bartlett pear prices. For some of those influences, such as quality, quantitative measures are not available; for others, such as varying proportions of different sizes in various seasons, data are inadequate. Although such price determinants are of marked interest, in the aggregate their price effects are less than the four major influences listed above. The relations between California Bartletts and certain other fresh fruits have been examined in the preceding section, "Relations between Pears and Other Fresh Fruits." Since a complete statistical explanation of the variation in Bartlett prices is impossible here, the present authors endeavor to present an analysis which will be of considerable aid in understanding the price behavior of, and in formulating marketing policies for, California fresh Bartletts.

TRENDS IN SUPPLIES AND PRICES OF PEARS

As a background for the subsequent discussion, trends in supplies and prices of several components of United States fresh pears are noted. Table 8 shows United States annual per-capita consumption of pears by five-year periods. From 1924-1928 to 1934-1938 per-capita consumption of pears, all forms in fresh equivalent, increased about 15 per cent, or

1.1 pounds. Of the increase, 45 per cent occurred in fresh pears, and 55 per cent in canned pears including those used in canned fruit salad and cocktail. Since interstate shipments and sales of California fresh Bartletts declined, the inference is that their per-capita consumption has

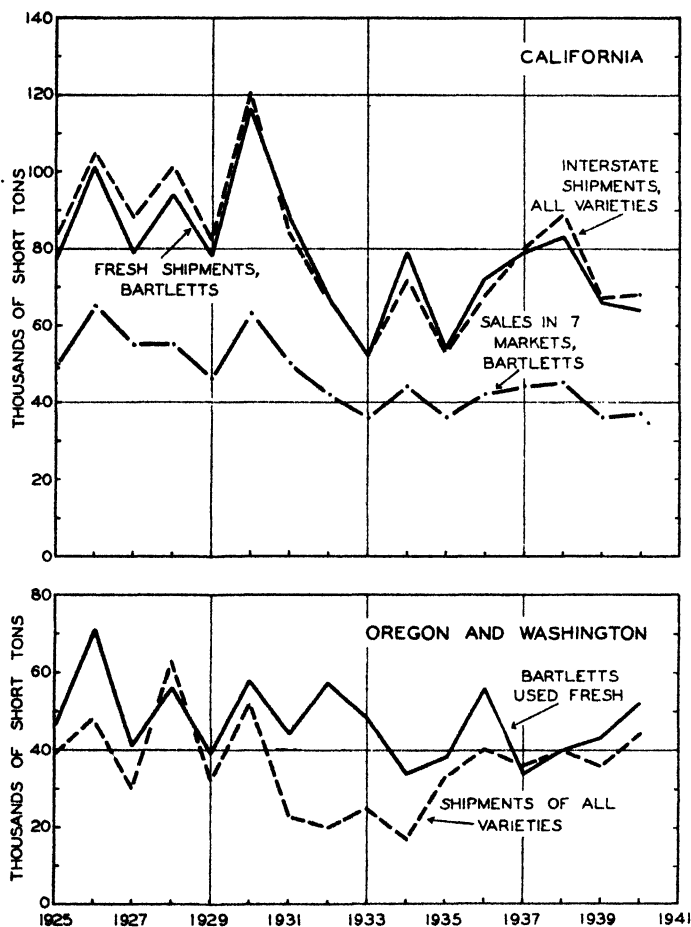


Fig. 8.—Supplies of California and Oregon and Washington fresh Bartlett pears, 1925–1940.

Data from table 27 (p. 317).

decreased. But part of the increase in canned pears came from increased use of California Bartletts for canning. The presumption is that the consumption of fresh California Bartletts is decreasing while their utilization for canning is increasing; and canning of California Bartletts is becoming relatively more important than fresh shipments.

Supplies of Pacific Coast Pears.—Figure 8 shows five supply series of Pacific Coast pears. The top deck contains three different series pertaining to California-produced fresh pears. One series represents interstate shipments of all California pears during the California Bartlett shipping

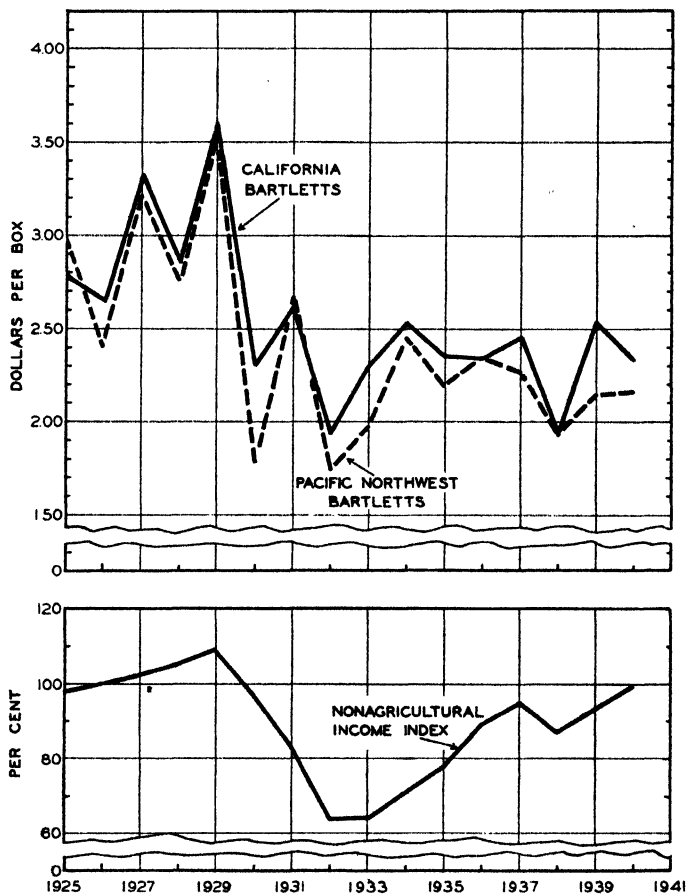


Fig. 9.—Auction prices of California and Pacific Northwest Bartlett pears, and index of United States nonagricultural income, 1925–1940.

Data from table 27 (p. 817).

season; the second series represents California Bartletts shipped fresh out of the state; and the third series represents California Bartletts sold on the seven major auction markets.⁸¹ The lower deck of figure 8 shows pear supplies from the Pacific Northwest (Oregon and Washington). One of the series indicates the volume of Pacific Northwest Bartletts used

⁸¹ New York, Chicago, Boston, Philadelphia, Pittsburgh, St. Louis, and Cincinnati.

fresh; the other series measures Pacific Northwest shipments of all varieties of pears only during the California Bartlett shipping season.

Prices of Pacific Coast Bartlett Pears.—Figure 9 shows two series of season's average prices of Pacific Coast Bartletts sold at auction. The California Bartlett prices are weighted averages of the season's prices on the seven major auction markets. The prices of the Pacific Northwest Bartletts are weighted-average prices on the New York auction. Pacific Northwest Bartletts are sold more in the Middle West than in the East; therefore New York auction prices may not be wholly representative of the bulk of sales. The prices shown in figure 9, however, serve for the purpose of indicating the general trends in the auction prices of California and Pacific Northwest Bartlett pears.

Although the two price series in figure 9 follow a somewhat similar pattern, and with few exceptions the year-to-year changes are in the same direction, certain important characteristics merit attention. During the sixteen-year period, from 1925 to 1940, with the exception of four years, California Bartlett prices were above those of Pacific Northwest Bartletts. No doubt California Bartletts generally sell at a premium over Pacific Northwest Bartletts because the former are considered to be of superior quality. To that extent California and Pacific Northwest pears are not perfect substitutes. The lower deck of figure 9 shows the movement of the index of nonagricultural income payments in the United States from July through October.

FACTORS AFFECTING CALIFORNIA BARTLETT PEAR PRICES

The data shown in figures 8 and 9 are used in the following statistical analysis of factors affecting California Bartlett prices. Table 9 contains five different equations, each representing different characteristics of statistical demand functions for California fresh Bartlett pears. The general reasoning underlying the equations may be expressed as follows: Economic theory and market observation give grounds for expecting an increase in California Bartlett fresh supplies or auction sales to be associated with a decrease in their auction prices. Since Pacific Northwest pears shipped during the California Bartlett season may be expected to compete in consumption with California Bartletts, it is also logical to expect increased Pacific Northwest shipments to be associated with decreases in California Bartlett prices. Furthermore, the demand for California Bartletts may be expected to be positively correlated with variations in the level of consumers' money incomes. Finally, there is no doubt that influences other than the volume of pear supplies and income affect California Bartlett prices. Some of those other influences may be grouped into a catchall variable which may be presumed to change

TABLE 9
CHARACTERISTICS OF STATISTICAL DEMAND FUNCTIONS FOR CALIFORNIA FRESH BARTLETT PEARS, 1925-1940
(Figures in parentheses are standard errors)

Equation no.	Dependent variable*	Constant term	Coefficients of independent variables*							Adjusted standard error of estimate, in dollars	Adjusted coefficient of multiple correlation
			X_2	X_3	X_4	X_5	X_6	X_7	t		
1.....	X_1	0.3453	-0.0006 (0.0032)				-0.0255 (0.0065)	+0.0354 (0.0072)		0.2783	0.7731
2.....	X_1	2.1410	-0.0084 (0.0046)			-0.0159 (0.0063)		+0.0203 (0.0046)	-0.0303 (0.0071)	0.2247	0.8689
3.....	X_1	0.9968	-0.0071 (0.0042)				-0.0207 (0.0063)	+0.0319 (0.0053)	-0.0222 (0.0064)	0.2003	0.8393
4.....	X_1	1.2804		-0.0186 (0.0096)			-0.0199 (0.0062)	+0.0318 (0.0051)	-0.0291 (0.0082)	0.1943	0.8966
5.....	X_1	0.9423			-0.0085 (0.0042)		-0.0191 (0.0063)	+0.0332 (0.0052)	-0.0240 (0.0064)	0.1924	0.8983

* X_1 = Weighted-average season's price of California fresh Bartlett pears on seven auction markets (dollars per box).

X_2 = California Bartlett pears shipped fresh out of California (thousands of tons).

X_3 = California Bartlett pears sold on seven auction markets (thousands of tons).

X_4 = Interstate shipments of all California pears during California Bartlett shipping season (thousands of tons).

X_5 = Oregon and Washington Bartlett pears used fresh (thousands of tons).

X_6 = Oregon and Washington shipments of all varieties of pears during California Bartlett shipping season (thousands of tons).

X_7 = Index of nonagricultural income payments in United States during July-October, 1924-1929 = 100 (percentages).

t = "Time" in years (origin, midpoint between 1932 and 1933).

Source of data:

Based on data in table 27 (p. 317).

smoothly over time. Such a factor shall be termed "time" in the statistical analysis. Simultaneously considering the several preceding concepts, the hypothesis may be set up that California Bartlett prices are a function of the volume of California Bartlett shipments, the volume of competing pear supplies, the level of consumers' money income, and "time." Whether the inclusion of "time" will statistically improve the analysis must be judged from the results. But it must be emphasized that "time" is a catchall variable, the specific components of which are not isolated. The problem is to choose those specific measures of pear supplies which, in combination with other price influences, will adequately account for the determination of California Bartlett prices, and measure the separate price effects of the individual price determinants.

Regression Analysis of Factors Affecting Prices.—Examination of the various multiple correlation coefficients and standard errors of the equations in table 9 indicates that equations 4 and 5 yield the best statistical explanation of the variation in California Bartlett prices, and equation 3 is only slightly less successful. In all of the equations in which "time" is an independent variable, its standard error is numerically less than the "time" net-regression coefficient. That is the statistical justification for retaining "time" in the analyses, and the omission of that variable would result in a lower adjusted multiple correlation coefficient. Equation 5 may be considered most desirable since both the Pacific Northwest shipments and those from California are for the same period, namely, during the California Bartlett shipping season. The signs of the net-regression coefficients are consistent with the expected theoretical relations between prices, supplies, and income outlined in the preceding paragraph. Furthermore, the net relation between price and "time" indicates that the demand for California fresh Bartletts has tended to decline during the past fifteen years—a situation which has been suspected by close observers of the industry.

The combined influences of the independent variables in equation 5 account for approximately 85 per cent of the variation in the dependent variable—season's weighted-average price of California fresh Bartletts on the seven chief auction markets. The inclusion of additional price influences such as supplies of related fruits, quality, and size of California Bartletts probably would decrease the amount of unexplained variation in the California Bartlett prices.

Since equation 5 and the others in table 9 are multiple linear regression equations, the question arises whether curvilinear net relations between the price and some of the independent variables would result in a better total fit or a better statistical explanation of the price variation. An answer to such a question may be obtained from examination of fig-

ure 10. The solid line in each of the four sections of figure 10 shows graphically the net statistical relation between the price and each of the independent variables, respectively, in equation 5. The dots, one for each year, are obtained as follows: To the price estimated from the net linear relation between the price and an independent variable is added the difference between the actual price and that calculated from the total regression equation. If significant curvilinearity existed between the price and an independent variable, the dots in the corresponding section would exhibit a curvilinear relation. Examination of distribution of dots in each of the four sections of figure 10 gives no basis for suspecting that net curvilinear relations would significantly improve the statistical fit. Hence, there is a basis for retaining the net linear relations expressed by equation 5 instead of introducing multiple curvilinear regression.

Results of Regression Analysis.—In the upper deck of figure 11 are compared graphically the California Bartlett actual prices, and those calculated from equation 5 in table 9. In general the two price series move closely together. The extent of discrepancy is evident from the figure. The lower deck of figure 11 shows the calculated partial relations between the price and each of the independent variables, respectively, in equation 5 of table 9. Thus, to restate the main results from the statistical analysis involving equation 5 the following are noted. During the 1925–1940 period, variation of four factors in combination accounted for 85 per cent of the variation in California Bartlett prices. The net statistical relations between the price and each of those factors may be expressed as follows: (1) With the other independent variables held constant, a change of 10,000 tons in the interstate shipments of all California pears during the California Bartlett shipping season was accompanied, on the average, by a change in the opposite direction of 8 cents a box in the auction price of California Bartletts; (2) with the other independent variables held constant, a change of 10,000 tons in Oregon and Washington shipments of all varieties of pears during the California Bartlett shipping season was accompanied, on the average, by a change in the opposite direction of 19 cents a box in the auction price of California Bartletts; (3) with the other independent variables held constant, a change of 10 points in the index of nonagricultural income payments was associated, on the average, with a change in the same direction of 33 cents a box in the auction price of California Bartletts; and (4) with the other independent variables held constant, a change of one unit or year in the “time” variable has, on the average, been accompanied by a change in the opposite direction of 2 cents a box in the auction price of California Bartletts. The relative importance of the price effects of the above four independent variables, respectively, may be indicated by the following

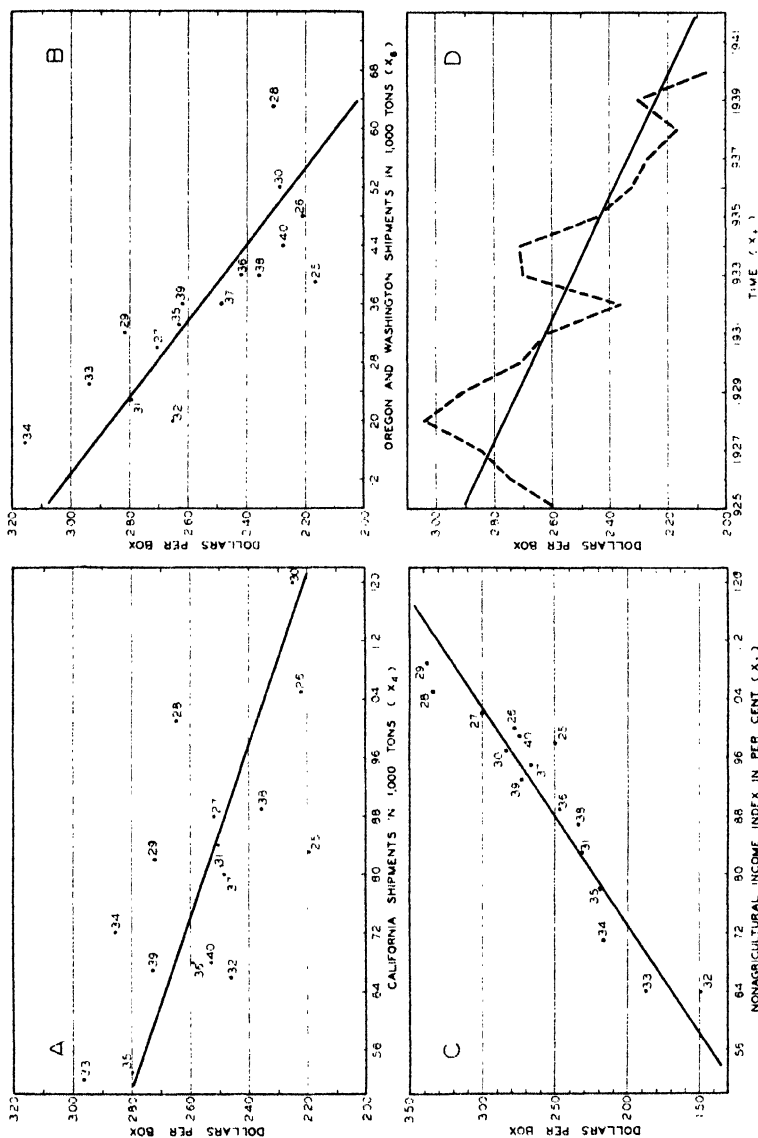


Fig. 10.—Net regression of California Bartlett pear price on: A, California shipments, $X'_{1,4} = 3.2314 - 0.0085 X_4$; B, Oregon and Washington shipments, $X'_{1,6} = 3.2450 - 0.0191 X_6$; C, nonagricultural income, $X'_{1,7} = -0.4286 + 0.0352 \bar{X}_7$; and D, "time," 1925-1940, $X'_{1,1} = 2.5512 - 0.0240 t$. Data based on table 9, equation 5.

coefficients of separate determination, adjusted for sign: 0.068 for pear shipments from California; 0.027 for shipments from Oregon and Washington; 0.532 for nonagricultural income; and 0.232 for the "time"

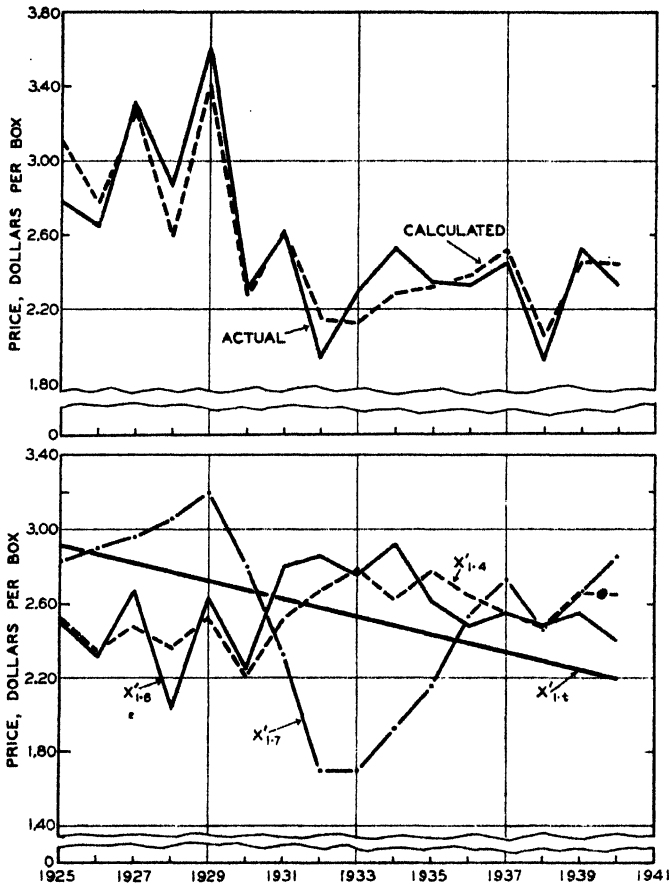


Fig. 11.—Actual and calculated auction prices of California Bartlett pears, and partial price effects of certain related factors, 1925–1940.

Data based on table 9, equation 5.

variable. Income has the relatively greatest price effect, and shipments from California have a relatively greater price effect than those from Oregon and Washington.

FORMULATION OF MARKETING POLICIES

Determination of Price Flexibilities.—In the formulation of marketing policies, special emphasis is attributed to the net or partial relation between proportional changes in price and associated proportional

changes in quantity marketed or sold. In this connection the concepts of elasticity of demand with respect to price, and price flexibility with respect to quantity, are of considerable importance. The former is equal to the percentage change in quantity divided by the corresponding percentage change in price, and the latter is equal to the percentage change in price divided by the corresponding percentage change in quantity, where the changes in price and quantity are small and all other factors remained unchanged. Theoretically, elasticity of demand is equal to the reciprocal of price flexibility, and vice versa. However, in a statistical demand function determined by the least-squares method of regression, the inverse relation between elasticity of demand and flexibility of price does not strictly hold. The difficulty is a statistical problem which need not be of concern here.²² In the multiple regression equation or statistical demand function discussed above (p. 282), price is the dependent variable, and therefore the appropriate measure of the relation between changes in price and quantity is the coefficient of price flexibility, indicated by the symbol ϕ . Again using equation 5 in table 9, it is stated that $\phi = \frac{\partial x_1}{\partial x_4} \cdot \frac{x_4}{x_1}$.

The first fraction of this expression is obtained directly from the regression equation 5 and is equal to the net regression of x_1 on x_4 , or 0.0085. The numerator and denominator of the second fraction of ϕ vary as different points on the statistical demand function are used in computing the coefficient of price flexibility. This condition is stated, since it is not usually made clear that in all types of demand functions, except where the net relation between price and quantity is a straight line on double logarithmic paper, the coefficient of price flexibility (and elasticity of demand) varies from point to point on the demand function. Thus price flexibility pertains to a point on a demand function and not to the entire function. Only when the coefficient is the same for all points on the demand function is it strictly correct to state that the demand curve has a certain price flexibility. In general, the coefficient of price flexibility (and elasticity of demand) pertains to a specific point on the demand function.

Entirely as a matter of convention, the coefficient of price flexibility (and elasticity of demand) is often computed for that point on the demand function whose coördinates contain the means of the independent variables. Using equation 5 in table 9, such a coefficient of price flexibility is computed. Substituting the means of the independent variables in the equation, the estimated price of \$2.55 is obtained, which is the denominator of the second fraction of $\phi = \frac{\partial x_1'}{\partial x_4} \cdot \frac{\bar{x}_4}{\bar{x}_1}$. The numerator of the second

²² See: Schultz, Henry. *The theory and measurement of demand*. p. 225-29. University of Chicago Press, Chicago. 1938.

fraction is the mean of x_4 , or 79.875; and $\frac{\partial x_1'}{\partial x_4}$ is the net regression of x_1 on x_4 , or -0.0085 . Substituting these values in the equation for ϕ , then $\phi = -0.2666$, which is equal to, at the point under consideration, the ratio of the relative change in price to the relative change in quantity with which it is associated, when the changes in price and quantity are small. Such a coefficient may be termed "average flexibility of price," although in fact it pertains to a single point on the statistical demand surface. The standard error of the coefficient may be computed³³ and is equal to ± 0.1097 . Hence for equation 5, the coefficient of "average flexibility of price" and its standard error are written as -0.2666 ± 0.1097 .

TABLE 10
CALCULATED COEFFICIENTS OF PRICE FLEXIBILITY, FOR CALIFORNIA
BARTLETT PEARS, 1925-1940

Year	Coefficient	Year	Coefficient
1925	-0.2274	1933	-0.2084
1926	-0.3231	1934	-0.2674
1927	-0.2288	1935	-0.1934
1928	-0.3327	1936	-0.2424
1929	-0.2039	1937	-0.2709
1930	-0.4499	1938	-0.3700
1931	-0.2731	1939	-0.2316
1932	-0.2614	1940	-0.2360

Source of data:

Computed from table 9, equation 5, by substituting the values of the independent variables which prevailed in the various years.

Price flexibilities have been computed for all the estimated prices during the 1925-1940 period. On the basis of equation 5, and substituting values of the independent variables which prevailed in the different years, the coefficients shown in table 10 have been obtained. The different coefficients illustrate the point noted above that the price flexibility varies from point to point on the demand surface. In this connection it is pertinent to mention that when the net relation between price and quantity is linear or the demand relation is expressed by a straight line, price flexibility varies inversely with the prices. High calculated prices are associated with low coefficients of price flexibility, and vice versa. This is necessarily characteristic of statistical demand functions yielding linear net relations between price and quantity.

Elastic Auction Demand for California Bartletts.—Since the coefficients of price flexibility for the individual years, and the "average flexibility of price" are all considerably less than 1, there is some basis

³³ See: Mosak, Jacob L. Standard error of the coefficient of elasticity of demand. Jour. Amer. Stat. Assoc. 34:353-61. June, 1939.

for concluding that the demand for California fresh Bartlett pears in eastern auction markets is elastic within the range of the present observations. Acceptance of such a conclusion means that, other factors remaining unchanged, price decreases associated with sales increases would yield increased gross returns from auction sales. That does not necessarily imply, however, that corresponding demand at the farm, packing-house, or shipping point is elastic. In fact, the reverse may be true. Here the present authors wish only to point out that the evidence indicates that within the range of their observations, the auction-market demand for California Bartletts is elastic; other factors remaining constant, low prices and large sales would yield larger gross auction returns than high prices and small sales. The above analysis, however, is not adequate for determining the behavior of growers' or shippers' net auction returns, which are equal to gross returns minus costs.

Historically, low prices of California Bartletts were not associated with a larger volume of auction sales than high prices, nor were gross auction returns in years of low prices greater than in years of high prices. That fact, however, does not invalidate the above statistical analysis since factors such as consumers' income, competing supplies of other pears, and tastes have changed over time. Determination of the statistical *net* relation between California Bartlett supplies and prices involves holding all the other factors unchanged.

Gross Returns from Auction Sales.—The question arises, how did gross returns from the seven chief auction markets vary since 1925? Not only has the volume of auction sales of California fresh Bartletts decreased over the 1925–1940 period, but since 1932 the auction prices have generally been at a relatively low level. Decreased sales in conjunction with low prices have resulted in decreased gross returns from auction sales. This situation is shown in figure 12, where gross returns from sales of California Bartletts on the seven chief auction markets are compared with the index of United States nonagricultural income payments for July–October. The two series are expressed in terms of 1924–1929 = 100. Both gross returns and nonagricultural income declined sharply after 1929 to a low in 1933, but gross returns declined substantially more. The significant relation between the two series occurred after the 1933 low point. The income index steadily rose until in 1937 it had reached 95 per cent of the 1924–1929 level; a drop in 1938 was followed by advances so that by 1940 the income index was at 99 per cent of the 1924–1929 level. This recovery was not evident in gross returns from auction sales. Since 1932, gross returns have fluctuated about a level of approximately 57 per cent of average annual returns for the 1924–1929 period. The significant indication is that the California fresh Bartlett industry,

judged on the basis of gross returns from the leading auction markets, has failed by far to regain its pre-Depression status. This situation may be due to many influences such as (1) increased competition from Pacific Northwest Bartletts which are on the market during the latter half of the California shipping period, (2) increased competition from other fresh fruits such as plums and peaches, (3) greater consumption of fall

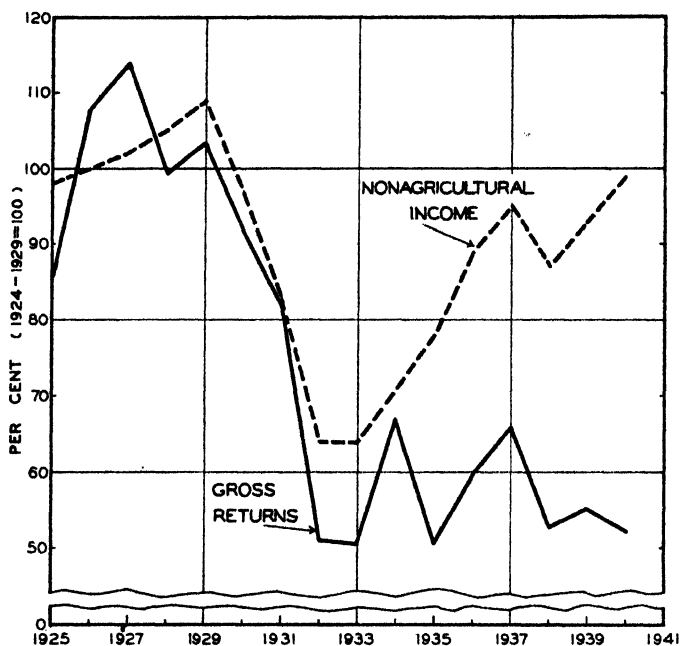


Fig. 12.—Gross returns from California Bartlett pears on seven major auction markets and United States nonagricultural income payments, 1925–1940.

Data from tables 27 and 28 (p. 317 and 319).

and winter pears with a decline in the consumption of California Bartletts, and (4) changes in consumers' tastes, attitudes, and habits. Clearly during the past decade the California fresh Bartlett industry has experienced a period during which important industry problems have become evident.

SUMMARY AND CONCLUSIONS

The pronounced seasonal variation in the weekly auction prices of California fresh Bartlett pears is directly related to the marked seasonal tendency in their shipments and auction sales. The seasonal patterns in sales and prices are inverse, but do not correspond perfectly; auction sales usually reach their maximum volume in the fourth or fifth week of the marketing season, and prices reach the lowest point during the in-

terval from the third to the sixth week. The seasonal variations in sales and prices do not perfectly correspond in any two seasons, but in all years the timing and magnitude of weekly changes in sales and prices follow a definite pattern. During the past two decades there has been a tendency towards smaller fluctuations in weekly auction sales and prices within the season. Prices for various weeks in the marketing season have deviated less from the season's average price in recent years than they did twelve or fifteen years ago. Such a change is most highly pronounced in the prices of the last quarter of the season. Hence there has been a shift in the pattern of seasonal variation in weekly prices. Although weekly prices of individual sizes of Bartletts vary among themselves, the prices of particular sizes follow a pattern of seasonal movement that is very similar to the seasonal variation in the weighted-average weekly prices of all sizes.

Season's average prices in various auction markets closely approximate each other. Although no single market consistently has the highest or lowest season's price, New York prices were either highest or second highest in all of the past sixteen years. The weekly prices in different auction markets follow broadly similar patterns of seasonal movement, but in some weeks prices in one market deviate widely from those in other markets. The weekly prices in each market appear to be influenced not only by its own position with respect to supplies of Bartletts and other fruits, but also by the situations in other markets and the price influences that affect all markets.

Examination of the relations of pears to other fresh fruit indicates that fresh plums and fresh peaches compete with California fresh Bartletts in consumption. The relation between Bartlett pears and oranges, however, is not so clear. There is considerable evidence that fresh pears and oranges are noncompeting in consumption. The character of such relations between pears and other fruits should be considered in the formulation and management of pear-marketing agreements and policies. In recent years there has been a decline in the sales and per-capita consumption of California Bartletts, and this decline may be partly due to the increase in the consumption of other fruits.

The annual changes in auction-market prices of California Bartletts during the 1925-1940 period have been primarily determined by variations in the following four major price influences: (1) the level of non-agricultural income payments in the United States; (2) the volume of California fresh pair interstate shipments during the California Bartlett shipping season; (3) the volume of Oregon and Washington interstate shipments of fresh pears during the California Bartlett shipping season; and (4) a straight-line "time" trend representing a persistent

shift in the auction-market demand for California fresh Bartletts. A change of 10,000 tons in California interstate shipments of pears during the California Bartlett season was accompanied, on the average, by a change in the opposite direction of about 8 cents a box in the auction price of California Bartletts. A change of 10,000 tons in Oregon and Washington shipments of pears during the California Bartlett shipping season was accompanied, on the average, by a change in the opposite direction of about 19 cents a box in the auction price of California Bartletts. A change of 10 points in the index of nonagricultural income payments was associated, on the average, with a change in the same direction of about 33 cents a box in the auction price of California Bartletts. Also during the 1925-1940 period there has occurred a decrease in the auction-market demand for California Bartletts. Other influences, such as the volume and prices of related fruits and products, the distribution of supplies in various market areas, the quality and size distribution of California Bartletts of the individual years, and the general level of wholesale prices have also affected auction-market prices of California Bartletts.

Statistical-demand analysis indicates that the auction-market demand for California Bartletts is elastic. Other influences remaining unchanged, a small decrease in auction price is associated with a proportionately larger increase in auction sales, and an increase in auction gross returns; a small increase in auction price is associated with a proportionately larger decrease in auction sales, and a decrease in auction gross returns.

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APPENDIX A

TRENDS IN RATIOS OF PRICES AND UNLOADS

As noted in the text (p. 268-69), tests 1 and 2 on related demands use prices and quantities pertaining to the New York market. The prices of California Bartletts, California plums (most important varieties), and California Valencia oranges are weighted-average auction-market prices for the two months July and August from 1924 through 1938. The corresponding quantities of the four fruits are unloads during July and August in New York. Although the data are referred to as pertaining to New York City, in fact they are representative of what may be termed the "New York market area." New York unloads supply the environs of New York, and the corresponding prices are a measure of the wholesale prices of the New York market area.

The auction prices of Bartletts, plums, and Valencia oranges were originally on a box basis, whereas the original wholesale peach prices were those of less-than-carlot 6-basket carriers. They were converted to dollars per 100 pounds in order to have the prices of the four fruits expressed in a common unit. For a similar reason all unloads were converted from a car basis to tons.

In using test 1 to determine the relations in consumption between pears and the three other fruits—plums, peaches, and oranges—the ratios were adjusted for secular trend. The trends adjusted for in both the price ratios and the quantity ratios were such that the adjusted ratios were substantially free of a rising or declining trend and fluctuated about a horizontal one. Schultz²⁴ used the ratio test (test 1) based on the relations between the coefficient of variation of the price ratios and the corresponding coefficient of the quantity ratios. Although he realized and stated that trends should be eliminated from the ratios before the coefficients of variation were computed, he actually did not do so on the grounds that later he was to apply "more refined tests to the same data." Nevertheless, he comments on some of his results with the suggestion that if the trends were eliminated from the ratios a different type of relation might result.

In the price ratios, the plum, peach, and orange prices, respectively, were divided by the pear price. Similarly, to obtain the quantity ratios the unloads of plums, peaches, and oranges, respectively, were divided by the pear unloads. The price ratios and unload ratios were adjusted for the trends expressed by the following mathematical equations where y

²⁴ Schultz, Henry. *The theory and measurement of demand*. p. 570-604. University of Chicago Press, Chicago. 1938.

stands for price ratios, x stands for unload ratios, and t stands for time in years :

- (1) Plum price to pear price,
 $y = 113.280 + 2.393t$; origin at 1923.
- (2) Plum unloads to pear unloads,
 $x = (21.186) (1.104)^t$; origin at 1924.
- (3) Peach price to pear price,
 $y = 65.939 + 3.088t$; origin at 1923.
- (4) Peach unloads to pear unloads,
 $x = 180.058 + 5.953t$; origin at 1923.
- (5) Orange price to pear price,
no trend eliminated.
- (6) Orange unloads to pear unloads,
 $x = 69.793 + 15.902t$; origin at 1923.

The actual price and quantity ratios were expressed as percentages of the above corresponding trends, and from the adjusted ratios were computed coefficients of variation and their standard errors. The final results were given and discussed on page 272.

APPENDIX B

**THE RELATIONS OF PEARS TO PLUMS, PEACHES, AND ORANGES
BASED ON LINEAR ARITHMETIC DEMAND FUNCTIONS⁸⁵**

In the section on "Relations between Pears and Other Fresh Fruits," test 2 (p. 273) is based on linear arithmetic demand functions given in table 11.

Equations 1, 3, and 5 in table 11 express the price of pears as functions of pear unloads; the unloads of the three other fruits, respectively; an index of New York state factory wages; and "time." Equations 2, 4, and 6 express the prices of plums, peaches, and oranges, respectively, as functions of pear unloads; the index of New York state factory wages; and "time." In each of the equations a closed system is assumed. Pears are undoubtedly related in demand with many fruits other than the three particular ones considered. The inclusion of more variables in the multiple regression equations would drastically reduce the number of degrees of freedom. The fits of the equations, as measured by the adjusted multiple correlation coefficients, adjusted standard errors of estimate, and standard errors of the net-regression coefficients, are only fair; but perhaps sufficient to give a qualitative indication of the related demands.

The unloads and prices in the multiple regression equations are the same data on which the ratio test 1 (p. 272) is based. They pertain to New York during July and August from 1924 through 1938. The measure of wages was computed from monthly factory wages in New York state based on the week in which the fifteenth of the month falls. An arithmetic average of the three monthly values—June, July, and August—may be viewed as a measure of income during the June–August interval. Although the prices and unloads are those of July and August, June wages were included with those of the following two months on the grounds that the effect of wages in June carries over into the immediately succeeding months. The factory wages are not wholly representative of purchasing power in the New York city area for at least two reasons. First, the factories from which the wage data are collected are not limited to the New York city area. Secondly, sources of income other than factory wages should be included in an adequate measure of consumers' income. To what extent the state factory wages are correlated with consumers' incomes in the New York city area is not known, but no doubt there is considerable correlation. Although the measure of income used is not all that one might desire, it is the best available index of income in New York. Probably if a more adequate measure of consumers' income in

⁸⁵ See: Hoos, Sidney. An investigation on complementarity relations between fresh fruits. *Jour. Farm Econ.* 23(2):421–33. May, 1941.

TABLE 11
DEMAND RELATIONS OF PEARS TO PLUMS, PEACHES, AND ORANGES IN NEW YORK, WITH PRICES AS DEPENDENT VARIABLES,
JULY AND AUGUST, 1924-1933
(Figures in parentheses are standard errors)

Equation no.	Dependent variable*	Constant term	Coefficients of independent variables*						Adjusted standard error of estimate, in dollars	Adjusted coefficient of multiple correlation
			z_1	z_2	z_3	z_4	w	t		
1.....	y_1	4.02065	-0.01490 (0.00416)	-0.00657 (0.00029)			+0.16942 (0.07137)	-0.23317 (0.06577)	0.5734	0.8774
2.....	y_2	3.15512	-0.01976 (0.00530)	-0.01447 (0.01183)			+0.31844 (0.09095)	-0.13067 (0.08381)	0.7307	0.8289
3.....	y_1	3.59350	-0.01534 (0.00426)		-0.00021 (0.00255)		+0.16230 (0.07274)	-0.26901 (0.05247)	0.5874	0.8709
4.....	y_2	3.02198	-0.00699 (0.00338)		-0.00933 (0.00232)		+0.24279 (0.06623)	-0.05250 (0.04777)	0.5348	0.8132
5.....	y_1	2.04480	-0.01486 (0.00406)			+0.00238 (0.00307)	+0.19277 (0.07649)	-0.29371 (0.05611)	0.5625	0.8823
6.....	y_4	4.45533	+0.00551 (0.00686)			-0.01934 (0.00519)	+0.27379 (0.12932)	+0.13835 (0.09486)	0.9510	0.8786

* z_1, z_2, z_3, z_4 = New York unloads of pears, plums, peaches, and oranges, respectively (in 100 tons).
 y_1, y_2, y_3, y_4 = New York wholesale prices of pears, plums, peaches, and oranges, respectively (in dollars per 100 pounds).
 w = New York state factory wages, June-August (in dollars per week).
 t = "time" in years (origin, July-August, 1931).

Source of data:

Based on data in tables 25 and 26 (p. 315 and 316).

TABLE 12
DEMAND RELATIONS OF PEARS TO PLUMS, PEACHES, AND ORANGES IN NEW YORK, WITH UNLOADS AS DEPENDENT VARIABLES,
JULY AND AUGUST, 1924-1938
 (Figures in parentheses are standard errors)

Equation no.	Dependent variable*	Constant term	Coefficients of independent variables*						Adjusted standard error of estimate, in 100 tons	Adjusted coefficient of multiple correlation
			y_1	y_2	y_3	y_4	w	t		
1.....	z_1	+ 163.41667	-19.17780 (18.81783)	-15.60794 (13.98160)			+ 8.51542 (3.87239)	-10.83552 (3.13866)	27.2546	0.5360
2.....	z_2	+ 30.96788	+ 3.42081 (12.72635)	- 8.08788 (9.45565)			+ 3.00319 (2.61855)	+ 4.16729 (2.12267)	18.4322	0.6039
3.....	z_1	+188.89526	-34.67716 (11.34896)	- 5.16405 (10.58628)			+ 7.48026 (3.96919)	-12.29063 (2.97629)	28.5653	0.5181
4.....	z_3	+199.22122	+22.55245 (17.35144)	-68.85655 (16.18577)			+14.22270 (6.06854)	+ 1.29049 (4.55048)	43.6735	0.7826
5.....	z_1	+183.46998	-39.09332 (11.21848)			- 2.47284 (6.62929)	+ 8.29994 (5.44414)	-13.46588 (3.99435)	28.7041	0.5161
6.....	z_4	+407.61233	- 3.48096 (14.65005)			-30.26976 (8.67536)	+ 4.51072 (7.12689)	+ 6.60536 (3.91985)	37.5759	0.8819

* z_1, z_2, z_3, z_4 = New York unloads of pears, plums, peaches, and oranges, respectively (in 100 tons).
 y_1, y_2, y_3, y_4 = New York wholesale prices of pears, plums, peaches, and oranges, respectively (in dollars per 100 pounds).
 w = New York state factory wages, June-August (dollars per week).
 t = "time" in years (origin, July-August, 1931).

Source of data:

Based on data in tables 25 and 26 (p. 315 and 316).

New York were available, the regression equations expressing the related demands would give a better fit.

Test 2 (p. 273) has two limitations. First is the assumption that utility is measurable; second is the assumption that the marginal utility of money is constant. This second limitation, which is equivalent to the assumption that the amount of money a consumer allocates to the good is such a small part of his income that the marginal degree of utility of his expenditures is constant, is not serious in connection with individual fresh fruits. The expenditure on consumption of fresh pears, peaches, plums, or oranges is probably such a small proportion of the total income of consumers that the marginal degree of utility of money may be neglected. But both limitations can be overcome by resorting to another test, the Slutsky conditions of related demand.⁸⁰

The Slutsky criterion of related demands has been applied here to the relations of pears to plums, peaches, and oranges. The equations in table 12 were used since the general theoretical conditions of the test may be calculated more easily when quantities are the dependent variables, although better fits were obtained with prices considered as the dependent variables.

The results for the two pairs of commodities, pears and plums, and pears and peaches, were disappointing since the two sides of the Slutsky-condition equations did not agree even in sign. This ambiguity may be due to the low correlations of at least one of the two multiple regression equations from which the relations of the pairs of goods are determined. In connection with pears and oranges, the results of the Slutsky condition are consistent with the previous tests, and the indications again are that pears and oranges are not competing in consumption.

⁸⁰ See: Hicks, J. R. *Value and capital*. p. 307-14. Oxford University Press, Oxford. 1939.

Also: Schultz, Henry. *The theory and measurement of demand*. p. 620-47. University of Chicago Press. Chicago, 1938.

For comments on the statistical significance of the Slutsky-condition results, see: Kozlik, Adolph. An investigation on complementarity relations between fresh fruits: A reply. *Jour. Farm Econ.* 23(2):654-56. August, 1941.

APPENDIX C

BASIC TABLES

TABLE 13
WEEKLY NEW YORK AUCTION SALES AND PRICES OF CALIFORNIA BARTLETT PEARS, 1916-1940

Desir- nated market- ing week no.*	1916			1917			1918			1919			1920		
	Week ending	Sales	Price per box	Week ending	Sales	Price per box	Week ending	Sales	Price per box	Week ending	Sales	Price per box	Week ending	Sales	Price per box
1	July 7	13,371	2.90	July 13	9,971	4.23	July 12	85	4.90	July 11	821	6.37	July 9	6,010	7.73
2	July 14	47,325	2.25	July 20	34,430	3.30	July 19	6,300	4.96	July 18	19,165	4.98	July 15	47,115	7.08
3	July 21	74,067	2.15	July 27	32,430	2.71	Aug. 2	23,220	4.97	Aug. 25	62,455	3.96	Aug. 23	90,545	4.95
4	Aug. 4	88,406	2.31	Aug. 10	105,200	2.82	Aug. 9	82,565	3.27	Aug. 25	73,590	4.00	Aug. 30	144,870	3.41
5	Aug. 11	87,965	2.87	Aug. 17	87,965	2.80	Aug. 16	82,150	3.28	Aug. 1	114,315	3.55	Aug. 13	106,090	3.78
6	Aug. 18	95,379	2.87	Aug. 24	88,142	3.21	Aug. 23	102,590	2.81	Aug. 1	114,315	3.55	Aug. 13	106,090	3.78
7	Sept. 4	64,240	3.06	Sept. 11	58,745	2.52	Sept. 10	75,090	2.23	Sept. 29	73,815	3.54	Sept. 27	68,555	5.72
8	Sept. 11	58,745	2.52	Sept. 18	58,745	2.52	Sept. 16	75,090	2.23	Sept. 29	73,815	3.54	Sept. 27	68,555	5.72
9	Sept. 18	58,745	2.52	Sept. 25	64,240	2.87	Sept. 24	75,090	2.23	Sept. 29	73,815	3.54	Sept. 27	68,555	5.72
10	Sept. 25	64,240	2.87	Oct. 2	35,154	2.31	Oct. 1	23,156	4.27	Sept. 12	24,520	5.27	Sept. 10	26,590	6.05
11	Oct. 9	17,242	2.85	Oct. 16	12,740	3.11	Oct. 15	11,075	4.40	Sept. 12	24,520	5.27	Sept. 10	26,590	6.05
12	Oct. 16	12,740	3.11	Oct. 23	2,275	3.07	Oct. 22	4,250	4.05	Sept. 12	24,520	5.27	Sept. 10	26,590	6.05
13	Oct. 23	2,275	3.07	Nov. 6	1,390	2.49	Nov. 5	1,390	3.28	Oct. 26	18,200	4.59	Oct. 24	23,563	5.00
14	Nov. 6	1,390	2.49	Nov. 13	240	3.50	Nov. 12	440	2.01	Oct. 26	18,200	4.59	Oct. 24	23,563	5.00
15	Season	518,087	2.63	Season	687,417	2.79	Season	663,157	3.05	Season	623,361	3.95	Season	672,710	4.51
1	July 15	5,760	6.17	July 14	94	7.59	June 29	35	7.25	June 27	154	6.56	June 26	40	15.88
2	July 22	25,435	5.31	July 21	5,670	6.56	July 13	8,155	5.23	July 11	6,780	6.16	July 10	34,985	5.58
3	Aug. 5	50,805	4.15	Aug. 4	44,885	4.32	July 13	61,555	3.16	July 11	58,810	3.98	July 10	34,985	5.58
4	Aug. 12	115,141	3.51	Aug. 11	83,800	3.26	Aug. 20	102,805	3.12	Aug. 18	62,490	3.72	Aug. 17	119,004	3.18
5	Aug. 19	121,655	3.09	Aug. 18	129,285	2.40	Aug. 27	156,720	2.55	Aug. 25	86,340	3.59	Aug. 24	114,680	2.57
6	Sept. 5	120,570	2.86	Sept. 4	130,090	2.51	Aug. 3	164,565	2.47	Aug. 1	91,060	3.87	Aug. 14	129,935	2.47
7	Sept. 12	28,515	4.43	Sept. 11	83,235	3.27	Aug. 3	119,735	2.65	Aug. 1	89,315	4.19	Aug. 14	144,820	2.26
8	Sept. 19	16,680	4.71	Sept. 18	106,165	3.24	Aug. 10	102,095	3.52	Aug. 1	89,315	4.19	Aug. 14	144,820	2.26
9	Sept. 26	15,680	4.71	Sept. 25	114,715	1.93	Aug. 17	65,045	3.57	Aug. 1	89,315	4.19	Aug. 14	144,820	2.26
10	Oct. 3	4,935	5.52	Oct. 2	88,565	2.68	Sept. 7	65,045	3.57	Sept. 29	66,105	4.10	Sept. 28	103,590	3.17
11	Oct. 10	1,810	5.38	Oct. 9	60,135	2.91	Sept. 14	43,130	3.90	Sept. 11	66,105	4.10	Sept. 10	87,990	2.96
12	Oct. 17	1,299	4.58	Oct. 16	10,265	3.56	Sept. 21	24,250	3.72	Sept. 18	35,285	3.85	Sept. 17	37,935	3.14
13	Season	661,753	3.55	Season	935,734	2.78	Season	989,307	3.04	Season	838,483	3.91	Season	1,077,998	2.83
14	Season	661,753	3.55	Season	935,734	2.78	Season	989,307	3.04	Season	838,483	3.91	Season	1,077,998	2.83
15	Season	661,753	3.55	Season	935,734	2.78	Season	989,307	3.04	Season	838,483	3.91	Season	1,077,998	2.83

(See last page of this table [p. 300] for footnotes and sources.)

Designated commodity and week ending	1926				1927				1928				1929				1930				Price per box
	Week ending	Sales	Price per box	Week ending	Sales	Price per box	Week ending	Sales	Price per box	Week ending	Sales	Price per box	Week ending	Sales	Price per box	Week ending	Sales	Price per box			
	June 25	boxes 1,340	dollars 6.22	July 8	boxes 1	dollars 10.25	July 6	boxes 6,070	dollars 5.35	July 19	boxes 2,180	dollars 6.81	July 11	boxes 17,990	dollars 4.70						
1	July 2	28,810	4.63	15	5,240	5.37	13	65,860	3.51	26	46,455	4.92	18	70,735	3.63						
2	7	87,485	3.40	22	46,750	4.24	20	106,580	2.99	Aug. 2	116,660	3.69	25	157,935	2.17						
3	13	183,680	2.96	29	112,365	3.93	27	130,440	2.25	9	116,660	3.69	Aug. 8	157,935	2.17						
4	20	183,845	2.42	5	139,580	4.66	Aug. 3	149,520	2.25	16	139,535	3.22	15	152,575	2.09						
5	Aug. 6	102,965	2.65	19	159,170	3.59	10	149,520	2.25	23	123,620	3.25	22	152,575	2.09						
6	13	107,895	3.17	26	176,680	2.77	17	93,935	3.48	30	129,950	3.78	29	151,785	2.15						
7	20	122,265	2.33	2	133,230	2.62	24	106,580	3.49	Sept. 6	90,635	3.74	29	151,785	2.15						
8	27	159,440	2.65	9	124,560	2.88	31	103,940	3.15	13	100,995	3.74	5	117,665	2.01						
9	Sept. 3	117,795	2.65	16	99,300	3.50	14	89,230	3.21	20	90,060	4.05	12	99,980	2.22						
10	10	77,785	3.48	23	96,375	3.93	21	65,195	3.46	27	70,380	3.64	19	80,350	2.46						
11	17	53,915	3.48	30	49,930	3.43	28	59,130	3.17	Oct. 4	24,005	4.15	26	74,370	2.70						
12	24	26,875	3.19	7	13,315	4.32	5	59,130	3.17	11	17,235	3.76	3	51,960	2.09						
13	Oct. 1	8,020	3.10	14	2,080	3.55	12	11,185	3.30	18	12,400	3.22	10	21,760	2.57						
14	8	1,715	3.19	21	115	2.73	19	795	3.15	Nov. 1	1,345	3.64	17	4,120	2.34						
15	Season	1,353,580	2.70	Season	1,250,661	3.37	Season	1,242,930	2.94	Season	1,044,373	3.71	Season	1,379,650	2.38						

TABLE 13—(Concluded)

Designated market- ing week no.*	1935		1937		1938		1939		1940			
	Week ending	Sales	Price per box	Week ending	Sales	Price per box	Week ending	Sales	Price per box	Week ending	Sales	Price per box
		boxes	dollars		boxes	dollars		boxes	dollars		boxes	dollars
1	July 3	545	2.41	July 17	1,572	3.36	July 16	1,315	3.05	July 1	250	2.86
2	July 10	17,415	3.32	July 24	37,399	3.58	July 30	23,170	3.58	July 8	2,810	3.70
3	July 17	76,875	2.35	Aug. 7	74,500	2.47	Aug. 6	73,325	2.52	July 15	19,345	3.27
4	July 24	92,920	2.22	Aug. 14	79,405	2.35	Aug. 13	86,258	1.94	July 22	68,688	2.46
5	Aug. 7	111,490	1.86	Aug. 21	86,410	2.28	Aug. 16	81,610	1.84	Aug. 5	68,688	2.32
6	Aug. 14	85,820	2.09	Aug. 28	90,598	2.41	Aug. 20	105,518	1.83	Aug. 12	59,950	2.51
7	Aug. 21	77,255	2.40	Sept. 4	82,905	2.42	Sept. 27	102,265	1.74	Aug. 19	70,190	2.63
8	Aug. 28	67,065	2.58	Sept. 11	85,915	2.55	Sept. 3	102,265	1.76	Sept. 2	62,905	2.71
9	Sept. 4	69,405	2.47	Sept. 18	57,925	2.66	Sept. 10	50,385	2.32	Sept. 9	64,135	2.57
10	Sept. 11	73,210	2.28	Sept. 25	62,675	2.46	Sept. 17	69,155	2.00	Sept. 16	71,010	2.51
11	Sept. 18	61,400	2.43	Oct. 2	74,815	2.26	Oct. 24	74,930	2.00	Sept. 23	46,515	2.50
12	Sept. 25	49,025	2.51	Oct. 9*	51,400	2.25	Oct. 16	47,220	2.13	Sept. 30	38,210	2.58
13	Oct. 2*	30,755	2.80	Oct. 16	47,220	2.89	Oct. 8	36,505	2.34	Oct. 7	37,305	2.73
14	Oct. 9	16,800	3.01	Oct. 23	14,825	2.97	Oct. 15*	31,560	2.34	Oct. 28	31,300	2.43
15	Oct. 16	7,755	3.06	Oct. 29	9,750	2.60	Oct. 21	18,310	2.46	Oct. 12	22,635	2.51
16	Oct. 23	6,670	2.64	Season	1,440	2.61	Season	1,440	2.61	Season	5,790	2.80
17	Season	508	2.54	Season	905,464	1.96	Season	905,464	1.96	Season	1,260	2.72
								83	2.56		5,725	1.73
								693,038	2.56		694,787	2.36

* First and last important marketing weeks of each season were determined by excluding those weeks having sales less than 2 per cent of the season's total; the first week is designated as marketing week 1, and the last week is designated by an asterisk.

Sources of data:

The basic data on daily auction sales and prices compiled from the *New York Daily Fruit Reporter* by various governmental agencies and by S. W. Shear.

TABLE 14

PERCENTAGE WEEKLY VOLUME OF SEASON'S AVERAGE WEEKLY NEW YORK AUCTION
SALES* OF CALIFORNIA BARTLETT PEARS, 1916-1940

Designated market- ing week no.†	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
		1	†		†		†	†	1	†	1	†	6
		15	8	1	9	8	6	9	7	7	23	4	
1	23	52	33	34	72	35	50	65	72	36	75	41	65
2	82	110	77	112	139	71	93	109	76	124	130	83	104
3	120	159	117	131	221	122	144	166	106	119	125	100	148
4	153	133	116	204	162	160	145	174	112	135	139	125	137
5	120	134	159	158	121	169	90	127	110	150	87	142	146
6	124	149	146	128	102	167	71	108	145	137	92	158	93
7	112	89	110	131	75	115	116	108	130	122	104	120	105
8	102	95	111	68	40	39	128	70	97	108	136	112	102
9	56†	53	33†	44	32	23†	97	46	81	91	100	88	93
10		26†	16	56	36†	6	67†	26†	89†	37	66	86	88
11		19	6	33†	17	3	11	12	16	41†	46†	45†	63
12		3	2	11	1	†	14	5	6	9	21	12	57†
13		†	1	2			8	1	†	4	5	2	11
14		†	1	†			2				1	†	1
15			†				1					†	1
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	
	2	16	7	3		2	†	1	2	2	6	1	
1	51	63	39	50	39	53	30	27	56	34	40	32	
2	85	105	97	86	85	103	76	120	111	115	158	77	
3	127	138	98	144	116	134	146	146	118	126	140	99	
4	152	113	106	141	140	120	142	175	128	119	123	133	
5	135	138	114	139	128	130	144	135	135	154	144	127	
6	141	120	139	131	109	101	147	121	123	150	128	150	
7	99	136	127	105	123	120	132	105	128	149	131	150	
8	110	105	113	106	130	106	137	109	86	74	146	132	
9	98	90	113	79	105	108	104	115	93	101	95	97	
10	77	72	135	67	120	99	88	96	111	110	78	113	
11	26†	67	79	50†	88	77	28	77	76	69	76	88	
12	19	52†	40†	24	76	50†	26†	48	34†	53	65	59	
13	13	20	19	8	42†	32	24	26†	22	46†	38	44	
14	1	4	10	6	26	6	14	12	14	20	38†	12	
15	†		1	1	17		4	10	1	2	12	10	
16			0	†				1			3	11	
17			0	0							†		
18			1	1									
19				0									
20				†									

* Data on sales for the various weeks of each year are percentages of the average weekly sales during the weeks in which most of the sales are made; the proportion of sales included in these important marketing weeks varies from 96 to 99 per cent and the number of weeks from 9 to 14.

† First and last important marketing weeks of each season were determined by excluding those weeks having sales less than 2 per cent of the season's total; the first week is designated as marketing week 1, and the last week is designated by a dagger.

‡ Less than 0.5 per cent.

Source of data:

Based on data in table 13.

TABLE 15

PERCENTAGE WEEKLY PRICES OF SEASON'S WEIGHTED-AVERAGE NEW YORK AUCTION
PRICES OF CALIFORNIA BARTLETT PEARS, 1916-1940

Designated market- ing week no.*	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent 358	per cent	per cent	per cent
1	110	152	151		171		273	238	168	208	230	305	
2	86	126	163	161	157	174	236	172	158	197	171	160	182
3	82	118	163	126	110	150	155	104	102	163	126	126	119
4	88	97	131	100	92	117	117	103	95	112	89	109	98
5	113	101	107	101	76	114	86	84	92	91	81	114	76
6	109	100	111	90	84	99	90	81	99	87	90	120	76
7	116	108	92	96	109	87	118	87	107	80	98	107	77
8	102	97	79	98	124	81	120	116	103	89	117	82	118
9	111	101	73	90	127	83	90	110	89	96	107	78	119
10		84	82	94	134	125	69	117	100	112	86	86	107
11		83	140	133	120	133	96	128	105	105	98	84	120
12		102	144	122	111	155	105	122	104	136	97	104	109
13		112	133	116	96	152	128	131	114	111	129	117	118
14		110	108	118	107	129	97	124	110	79	118	128	108
15		53	66	93			102	104	73	97	115	106	109
		129	94	91			79				118	81	130
			70				99					63	107
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	
1	184	197	145	196		143	162	103	135	156	145	148	
2	132	153	124	140	119	109	142	141	144	129	128	123	
3	96	90	114	96	90	88	93	94	94	94	91	107	
4	87	87	110	91	103	99	100	79	82	93	98	92	
5	88	97	99	79	103	95	103	89	97	93	103	97	
6	102	90	87	84	104	104	105	102	97	89	106	97	
7	102	90	85	97	113	100	96	110	102	90	100	90	
8	101	84	99	100	96	99	91	105	107	118	98	99	
9	109	93	94	110	94	98	89	97	99	102	101	106	
10	98	103	96	100	92	109	91	103	91	102	101	101	
11	112	113	92	113	98	103	109	107	90	109	107	93	
12	101	88	129	124	103	113	116	119	116	119	95	102	
13	87	108	143	136	94	116	101	128	119	119	96	106	
14	98	98	134	137	100	95	95	130	112	118	96	124	
15	75		136	115	96		99	112	124	133	109	109	
16			...	80				108			106	75	
17			...	...							104		
18			98	72									
19				...									
20				48									

* First important marketing week of each season was determined by excluding those weeks having sales less than 2 per cent of the season's total.

Source of data:

Based on data in table 13.

TABLE 16

SEASON'S WEIGHTED-AVERAGE NEW YORK AUCTION PRICES OF CALIFORNIA BARTLETT PEARS AND DEVIATIONS THEREFROM, BY WEEKS OR GROUPS OF WEEKS, 1916-1940

Year	Season's average	Deviations from season's average*					
		Through second week	Third and fourth weeks	Fifth week	Through fifth week	Sixth-eighth week	Ninth-eleventh week
	<i>dollars per box</i>	<i>dollars per box</i>	<i>dollars per box</i>	<i>dollars per box</i>	<i>dollars per box</i>	<i>dollars per box</i>	<i>dollars per box</i>
1916.....	2.63	-0.24	-0.39	0.34	-0.19	0.24	....
1917.....	2.79	0.17	0.02	0.23	0.11	-0.15	-0.18
1918.....	3.05	1.29	0.27	-0.23	0.35	-0.67	1.23
1919.....	3.95	0.27	-0.22	-0.14	-0.09	-0.24	-0.97
1920.....	4.51	0.01	-0.94	0.42	-0.43	1.20	0.53
1921.....	3.55	1.10	0.20	-0.46	0.18	-0.47	1.38
1922.....	2.78	0.98	-0.32	0.49	0.18	-0.32	-0.03
1923.....	3.04	0.20	-0.53	-0.39	-0.30	0.42	0.81
1924.....	3.91	0.06	-0.18	0.28	0	-0.12	0.21
1925.....	2.83	0.76	-0.31	-0.57	-0.07	-0.05	0.38
1926.....	2.70	0.26	-0.38	-0.05	-0.08	-0.04	0.12
1927.....	3.37	0.54	0.59	0.22	0.47	-0.61	-0.05
1928.....	2.94	0.26	-0.72	-0.69	-0.43	0.43	0.46
1929.....	3.71	0.73	-0.33	-0.46	-0.10	0.06	0.20
1930.....	2.38	0.97	-0.26	-0.07	0.18	-0.27	0.06
1931.....	2.67	0.15	0.32	-0.03	0.18	-0.27	-0.16
1932.....	2.01	0.68	-0.14	-0.43	-0.01	-0.15	0.15
1933.....	2.31	0.18	-0.07	0.07	0.03	0.09	-0.12
1934.....	2.56	0.03	-0.18	-0.13	-0.11	0.02	0.09
1935.....	2.37	0.61	-0.09	0.06	0.09	-0.06	-0.18
1936.....	2.35	0.20	-0.33	-0.26	-0.18	0.13	0.04
1937.....	2.49	0.36	-0.18	-0.08	0.01	0.04	-0.17
1938.....	1.96	0.12	-0.13	-0.13	-0.06	-0.10	0.07
1939.....	2.56	0.09	-0.15	0.07	-0.02	0.03	0.07
1940.....	2.36	0.44	-0.04	-0.06	0.07	-0.11	0.01

* Based on weighted-average price for week or group of weeks.

Source of data:

Based on data given in table 13.

TABLE 17

RELATIVE AVERAGE WEEKLY VOLUME OF NEW YORK AUCTION SALES OF CALIFORNIA
BARTLETT PEARS BY GROUPS OF WEEKS AS PERCENTAGES OF
SEASON'S TOTAL SALES, 1916-1940

Year	Averages for weeks					
	First and second	Third and fourth	Fifth	First- fifth	Sixth- eighth	Ninth- eleventh
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
1916	5.8	15.6	13.3	11.3	12.5	0.0
1917	7.8	14.0	12.9	11.3	10.7	3.2
1918	5.8	12.4	17.0	10.7	13.1	1.9
1919	6.6	15.0	14.2	11.5	9.8	4.0
1920	10.2	18.6	11.8	13.9	7.0	2.8
1921	5.8	15.4	18.4	12.1	11.7	1.2
1922	6.8	13.8	8.6	10.0	10.1	5.6
1923	8.5	16.6	12.4	12.5	9.3	2.7
1924	7.2	10.6	10.7	9.3	12.0	5.4
1925	7.1	11.4	13.4	10.1	10.9	5.0
1926	8.9	11.5	7.6	9.7	9.6	6.1
1927	5.6	10.0	12.7	8.8	11.6	6.5
1928	6.9	11.6	12.0	9.8	8.2	6.7
1929	6.0	12.3	11.8	9.7	10.3	5.9
1930	6.8	10.1	11.1	9.0	9.7	6.2
1931	5.4	8.3	9.2	7.3	10.2	8.8
1932	6.0	12.4	12.2	9.8	10.0	5.7
1933	4.6	9.6	9.6	7.9	9.0	7.7
1934	6.3	10.2	10.5	8.7	8.8	7.6
1935	4.2	11.6	11.6	8.7	11.2	5.9
1936	5.6	12.1	10.1	9.1	8.4	7.3
1937	6.7	10.0	10.9	8.8	9.1	7.5
1938	5.6	9.2	11.7	8.3	9.4	7.0
1939	7.0	9.2	10.1	8.5	9.5	5.9
1940	4.1	8.7	9.5	7.0	10.8	7.4

Source of data:

Simple averages of relative sales for corresponding weeks computed from data in table 13.

TABLE 18
WEEKLY NEW YORK AUCTION PRICES PER BOX OF CALIFORNIA
BARTLETT PEARS, BY SIZES, 1936-1939

Week ending	Number of pears per box*												Average of all sizes
	Larger than 70	70	80	90	100	110	120	135	150	165	180	195	
1936:	dollars	dollars	dollars	dollars	dollars	dollars	dollars	dollars	dollars	dollars	dollars	dollars	dollars
July 10	.....	.....	.....	.....	.....	3 45	3 97	3 82	3 44	3 34	3 29	.....	3 34
July 17	.....	.....	.....	.....	2 37	2 81	2 80	2 57	2 39	2 36	2 38	.....	2 39
July 24	.....	.....	.....	1 77	2 40	2 47	2 29	2 23	2 21	2 23	2 28	.....	2 24
July 31	.....	.....	1 70	1 80	1 88	1 90	1 84	1 82	1 84	1 87	1 93	.....	1 87
Aug. 7	.....	2 30	2 20	2 03	2 09	2 04	2 00	1 99	2 09	2 11	2 19	.....	2 09
Aug. 14	1 60	2 22	2 15	2 31	2 22	2 04	2 22	2 29	2 39	2 43	2 52	.....	2 39
Aug. 21	.....	2 23	2 32	2 38	2 28	2 28	2 35	2 45	2 61	2 67	2 78	.....	2 58
Aug. 28	2 10	2 30	2 38	2 24	2 21	2 22	2 26	2 36	2 51	2 63	2 63	.....	2 49
Sept. 4	1 86	2 05	2 04	2 06	1 99	1 98	2 06	2 20	2 36	2 43	2 42	.....	2 28
Sept. 11	1 92	2 07	2 21	2 24	2 18	2 19	2 24	2 35	2 51	2 60	2 62	.....	2 44
Sept. 18	1 90	2 07	2 14	2 17	2 17	2 20	2 31	2 43	2 62	2 71	2 73	.....	2 51
Sept. 25	2 38	2 42	2 45	2 50	2 50	2 50	2 56	2 73	2 91	3 00	3 01	.....	2 81
Oct. 2	2 65	2 88	2 83	2 83	2 85	2 84	2 86	2 97	3 09	3 13	3 09	.....	3 01
Oct. 9	.....	2 78	3 05	3 02	3 03	2 95	2 96	3 01	3 13	3 12	3 07	.....	3 06
Oct. 16	.....	2 89	2 80	2 86	2 85	2 81	2 70	2 57	2 64	2 66	2 67	.....	2 64
Season	2 04	2 29	2 29	2 29	2 22	2 21	2 22	2 30	2 36	2 36	2 42	.....	2 34
1937:													
July 24	.....	.....	.....	2 47	2 80	3 43	3 53	3 33	3 38	3 43	3 56	.....	3 43
July 31	.....	.....	.....	2 70	2 56	2 48	2 42	2 34	2 44	2 49	2 63	.....	2 47
Aug. 7	.....	.....	.....	2 66	2 26	2 20	2 14	2 20	2 37	2 48	2 69	.....	2 36
Aug. 14	.....	1 70	1 99	2 13	2 04	2 01	2 06	2 15	2 35	2 48	2 69	.....	2 29
Aug. 21	.....	2 05	2 11	2 21	2 16	2 14	2 21	2 34	2 51	2 58	2 65	.....	2 42
Aug. 28	.....	2 52	2 27	2 25	2 18	2 18	2 24	2 34	2 48	2 55	2 63	.....	2 43
Sept. 4	1 94	2 04	2 17	2 20	2 21	2 25	2 36	2 50	2 67	2 74	2 79	.....	2 56
Sept. 11	2 15	2 36	2 38	2 33	2 35	2 39	2 49	2 59	2 75	2 82	2 85	.....	2 67
Sept. 18	2 12	2 19	2 19	2 13	2 17	2 22	2 31	2 40	2 52	2 60	2 62	.....	2 45
Sept. 25	2 03	2 03	2 12	2 11	2 09	2 10	2 16	2 24	2 33	2 34	2 31	.....	2 26
Oct. 2	2 30	2 20	2 08	2 00	2 00	2 02	2 11	2 24	2 36	2 37	2 30	.....	2 25
Oct. 9	2 55	3 03	2 83	2 81	2 77	2 69	2 78	2 89	3 03	3 01	2 88	.....	2 89
Oct. 16	2 69	2 75	2 84	2 87	2 90	2 91	2 96	3 06	3 17	3 03	2 88	.....	2 97
Oct. 23	.....	2 56	2 57	2 52	2 52	2 55	2 63	2 71	2 90	2 90	2 98	.....	2 70
Oct. 30	3 40	2 85	2 93	2 95	2 96	2 88	3 05	3 19	3 32	3 29	3 23	.....	3 11
Season	2 16	2 38	2 28	2 25	2 23	2 24	2 30	2 39	2 53	2 63	2 72	.....	2 49
1938:													
July 23	.....	.....	.....	.....	2 35	2 54	2 86	3 26	3 11	2 83	2 56	2 25	2 51
July 30	.....	.....	1 00	1 00	1 00	2 14	3 06	2 69	2 21	2 00	1 88	1 77	1 95
Aug. 6	.....	.....	.....	.....	2 99	2 66	2 63	2 13	1 89	1 81	1 79	1 77	1 84
Aug. 13	.....	.....	.....	2 75	2 56	2 48	2 20	1 88	1 80	1 79	1 84	1 84	1 83
Aug. 20	.....	.....	.....	2 02	2 04	2 17	1 98	1 80	1 81	1 81	1 85	1 84	1 83
Aug. 27	.....	.....	2 17	2 13	2 11	1 87	1 75	1 71	1 73	1 71	1 72	1 66	1 72
Sept. 3	.....	.....	1 77	1 74	1 74	1 61	1 66	1 70	1 78	1 78	1 80	1 67	1 74
Sept. 10	.....	2 15	2 17	2 31	2 16	2 09	2 15	2 24	2 37	2 39	2 45	2 37	2 32
Sept. 17	2 05	2 11	2 06	2 00	1 89	1 87	1 93	2 00	2 14	2 17	2 23	2 18	2 10
Sept. 24	.....	1 86	1 91	1 93	1 89	1 85	1 88	1 97	2 08	2 10	2 12	2 07	2 03
Oct. 1	2 20	2 07	2 08	2 07	2 13	2 07	2 06	2 14	2 19	2 15	2 12	2 00	2 13
Oct. 8	.....	3 00	2 50	2 40	2 31	2 23	2 21	2 30	2 38	2 38	2 39	2 26	2 34
Oct. 15	.....	2 15	2 22	2 40	2 30	2 19	2 20	2 28	2 39	2 40	2 40	2 33	2 34
Oct. 22	.....	.....	.....	2 52	2 46	2 31	2 27	2 31	2 39	2 34	2 25	2 06	2 31
Oct. 29	.....	.....	.....	.....	2 65	2 65	2 78	2 77	2 75	2 67	2 46	2 21	2 62
Season	2 12	2 06	2 01	2 05	2 01	1 93	1 96	1 96	1 99	1 96	1 96	1 93	1 96

(Table concluded on p. 306; footnotes at end of table.)

TABLE 18—(Concluded)

Week ending	Number of pears per box*												Average of all sizes
	Larger than 70	70	80	80	100	110	120	135	150	165	180	195	
1939:	dol-lars	dol-lars	dol-lars	dol-lars	dol-lars	dol-lars	dol-lars	dol-lars	dol-lars	dol-lars	dol-lars	dol-lars	dol-lars
July 15	.....	.....	.....	.....	3.80	3.38	3.78	3.50	3.30	3.25	3.24	3.14	3.27
July 22	.....	.....	1.35	1.35	2.52	2.94	2.70	2.45	2.45	2.45	2.48	2.21	2.46
July 29	.....	.....	2.20	2.48	2.61	2.52	2.41	2.27	2.32	2.32	2.36	.....	2.32
Aug. 5	.....	.....	2.41	2.33	2.40	2.37	2.40	2.41	2.52	2.53	2.56	.....	2.51
Aug. 12	.....	.....	2.35	2.51	2.45	2.42	2.45	2.50	2.65	2.71	2.70	.....	2.63
Aug. 19	2.10	2.35	2.38	2.35	2.39	2.41	2.47	2.60	2.75	2.79	2.80	2.76	2.71
Aug. 26	.....	2.20	2.22	2.24	2.25	2.26	2.35	2.45	2.60	2.68	2.68	2.61	2.58
Sept. 2	.....	2.11	2.19	2.35	2.32	2.28	2.31	2.40	2.54	2.57	2.60	2.41	2.51
Sept. 9	2.52	2.33	2.66	2.71	2.62	2.46	2.44	2.52	2.64	2.65	2.59	2.30	2.59
Sept. 16	.....	.....	2.67	2.81	2.84	2.57	2.45	2.55	2.62	2.61	2.56	2.36	2.58
Sept. 23	.....	2.46	2.76	2.94	2.90	2.63	2.51	2.65	2.76	2.80	2.75	2.41	2.72
Sept. 30	.....	2.62	2.98	2.99	2.80	2.46	2.34	2.41	2.40	2.46	2.43	1.99	2.43
Oct. 7	.....	.....	2.36	2.52	2.67	2.40	2.34	2.51	2.59	2.54	2.39	1.52	2.47
Oct. 14	.....	.....	2.10	2.59	2.66	2.31	2.19	2.39	2.50	2.54	2.46	.....	2.45
Oct. 21	.....	.....	.....	3.15	2.86	2.81	2.59	2.78	2.86	2.88	2.71	.....	2.80
Season	2.31	2.25	2.39	2.46	2.46	2.49	2.41	2.48	2.58	2.60	2.61	2.37	2.56

* Sizes smaller than 180 in 1936 and 1937 and smaller than 195 in 1938 and 1939 and odd sizes between 70 and 180 are not listed here separately but are included in "average of all sizes."

Sources of data:

1936 and 1937: from United States Agricultural Adjustment Administration Division of Marketing and Marketing Agreements. California Bartlett Pears, 1937. General Crops Section. San Francisco. Econ. No. 5:12-15. December, 1937. (Mimeo.)

1938: from United States Agricultural Adjustment Administration Division of Marketing and Marketing Agreements. New York Auction Market Sales and Prices of California Bartlett Pears, by Sizes, by Weeks, 1938 Season. General Crops Section. San Francisco. Econ. No. 8:1-3. February, 1939. (Mimeo.)

1939: from Studt, Ward B. California Bartlett Pears, 1939. U. S. Agricultural Adjustment Administration Division of Marketing and Marketing Agreements, General Crops Section. San Francisco. Econ. No. 12: Table 1. January, 1940. (Mimeo.)

TABLE 19
WEEKLY VOLUME OF NEW YORK AUCTION SALES OF CALIFORNIA BARTLETT PEARS, BY SIZES, 1936-1939

Week ending	Number of pears per box*												Total of all sizes
	Larger than 70	70	80	90	100	110	120	135	150	165	180	195	
	boxes	boxes	boxes	boxes	boxes	boxes	boxes	boxes	boxes	boxes	boxes	boxes	boxes
1936:													
July 10.....	0	0	0	0	0	1	32	363	2,154	5,098	8,676	.....	16,390
July 17.....	0	0	0	0	5	21	527	4,266	15,415	27,530	31,145	.....	78,946
July 24.....	0	0	0	0	43	268	2,034	9,900	20,982	31,165	24,098	.....	92,276
July 31.....	0	0	0	0	249	690	4,204	15,218	22,995	30,506	25,406	.....	113,017
Aug. 7.....	0	0	1	25	777	1,773	5,809	14,518	22,995	24,906	16,412	.....	88,052
Aug. 14.....	0	1	16	135	421	2,364	5,363	11,951	19,337	21,005	15,759	.....	77,890
Aug. 21.....	0	23	102	443	1,626	2,454	5,293	11,593	17,695	17,863	10,065	.....	70,703
Aug. 28.....	0	23	132	536	1,637	2,553	5,871	13,660	18,531	16,081	10,697	.....	70,005
Sept. 4.....	2	80	445	1,018	2,587	3,901	7,258	14,011	17,800	14,795	6,475	.....	60,812
Sept. 11.....	3	96	408	991	2,287	3,252	4,390	11,807	13,172	10,718	6,475	.....	48,208
Sept. 18.....	2	92	514	957	2,104	3,213	4,390	11,807	13,172	10,718	6,475	.....	48,208
Sept. 25.....	11	99	371	608	1,163	1,852	2,905	6,854	4,651	2,969	3,155	.....	30,753
Oct. 2.....	1	56	213	345	74	962	1,771	3,517	2,003	1,352	1,663	.....	16,883
Oct. 9.....	0	24	28	74	134	378	742	2,307	2,003	1,352	1,663	.....	7,753
Oct. 16.....	0	7	29	63	129	187	336	2,158	2,020	1,255	449	.....	6,683
Season.....	32	505	2,372	5,694	15,075	23,930	52,061	136,122	215,039	225,599	169,065	.....	848,553
1937:													
July 24.....	0	0	0	3	10	57	576	4,251	9,758	14,955	7,573	.....	37,360
July 31.....	0	0	0	2	69	503	2,760	11,960	20,596	25,901	10,938	.....	73,714
Aug. 7.....	0	0	0	15	508	1,702	6,845	17,527	24,687	25,901	6,349	.....	79,956
Aug. 14.....	0	1	23	162	443	2,459	9,511	21,471	25,609	18,573	5,598	.....	87,013
Aug. 21.....	0	1	102	443	2,095	3,736	9,547	21,414	24,897	17,433	7,132	.....	91,233
Aug. 28.....	0	2	145	487	2,021	3,547	7,622	18,177	23,423	16,833	8,236	.....	80,581
Sept. 4.....	17	150	630	1,562	4,129	5,150	10,339	19,102	22,022	15,295	7,973	.....	86,530
Sept. 11.....	1	176	407	1,061	2,701	3,174	5,548	11,657	16,577	11,048	5,599	.....	57,864
Sept. 18.....	3	155	780	1,635	3,337	3,733	6,479	12,605	17,203	11,204	8,175	.....	63,555
Sept. 25.....	32	410	925	1,787	3,596	4,516	7,951	13,971	20,265	13,449	8,175	.....	75,082
Oct. 2.....	15	275	604	1,166	2,821	3,088	5,267	10,283	13,515	9,017	2,939	.....	52,208
Oct. 9.....	4	352	323	1,028	1,755	2,755	3,692	4,636	4,525	3,458	2,939	.....	23,259
Oct. 16.....	6	89	219	570	1,068	1,474	2,340	8,253	2,269	1,678	1,171	.....	14,850
Oct. 23.....	0	22	111	203	431	606	1,238	1,703	1,065	523	151	.....	6,155
Oct. 30.....	1	4	31	48	83	93	142	193	116	58	21	.....	790
Season.....	83	1,548	4,301	9,781	26,574	37,626	79,298	172,321	227,090	179,049	84,578	.....	852,148

* Sizes smaller than 180 in 1936 and 1937 and smaller than 195 in 1938 and 1939 and odd sizes between 70 and 180 are not listed here separately but are included in the "Total of all sizes." (Table concluded on p. 308.)

TABLE 19—(Continued)

Week ending	Number of pears per box*												Total of all sizes boxes
	Larger than 70 boxes	70 boxes	80 boxes	90 boxes	100 boxes	110 boxes	120 boxes	135 boxes	150 boxes	165 boxes	190 boxes	195 boxes	
1938:													
July 23	0	0	0	0	4	14	20	175	1,114	4,210	7,826	7,900	22,785
July 30	0	0	1	1	7	29	172	1,765	9,670	21,031	27,871	15,418	78,214
Aug. 6	0	0	0	0	4	61	536	5,003	17,219	29,121	27,066	7,634	86,911
Aug. 13	0	0	0	0	17	190	1,491	8,705	21,032	28,228	18,203	2,827	81,207
Aug. 20	0	0	0	4	9	485	3,340	13,378	26,265	32,012	23,795	4,856	104,748
Aug. 27	0	0	0	0	52	1,339	5,631	16,309	25,644	27,811	18,675	5,418	102,145
Sept. 3	0	0	6	335	1,468	3,294	7,990	18,445	25,941	23,684	15,124	4,787	102,401
Sept. 10	0	0	72	249	1,139	2,059	5,181	9,523	12,304	10,523	6,740	2,370	50,488
Sept. 17	1	23	132	408	1,406	2,574	6,435	13,270	17,944	14,728	8,690	3,152	69,171
Sept. 24	0	0	226	600	1,896	3,199	7,350	13,270	18,772	15,564	9,737	4,150	74,985
Oct. 1	1	39	198	535	1,279	1,697	4,334	8,195	10,483	9,681	6,098	3,517	47,983
Oct. 8	0	3	26	160	595	1,041	2,886	6,395	7,036	7,540	4,587	2,255	36,522
Oct. 15	0	1	24	123	690	1,133	3,140	5,877	7,540	7,540	4,587	1,416	31,626
Oct. 22	0	0	0	24	138	283	833	1,736	2,545	4,342	2,617	803	13,348
Oct. 29	0	0	0	0	1	2	26	137	339	583	237	128	1,438
Season.....	2	89	714	2,560	9,330	17,370	49,436	122,834	207,635	238,359	182,771	66,707	905,202
1939:													
July 15	0	0	0	0	6	12	99	1,067	3,435	7,102	6,977	223	19,199
July 22	0	0	3	2	16	72	1,296	7,927	19,275	26,685	20,799	22	76,977
July 29	0	0	6	33	115	473	1,950	10,305	19,571	24,682	16,510	0	75,324
Aug. 5	0	0	10	113	247	908	1,912	9,083	15,653	17,237	14,772	0	60,985
Aug. 12	0	0	36	145	772	1,062	3,572	11,504	17,169	17,080	16,698	0	69,180
Aug. 19	2	19	93	362	652	1,412	4,489	9,389	14,600	15,301	14,697	1,107	62,443
Aug. 26	0	42	152	545	1,285	1,874	4,542	10,120	15,607	15,270	14,107	1,433	64,025
Sept. 2	0	19	125	337	1,205	1,511	4,071	10,907	17,943	18,690	15,545	1,477	71,472
Sept. 9	2	8	59	248	591	1,001	2,105	5,707	12,056	12,303	11,313	1,600	46,933
Sept. 16	0	0	23	95	237	505	1,594	4,559	9,794	10,012	9,860	1,455	38,434
Sept. 23	0	8	64	128	342	666	2,595	6,343	9,332	8,553	7,457	788	37,207
Sept. 30	0	2	27	74	239	445	1,513	3,702	8,121	9,283	8,433	724	31,569
Oct. 7	0	0	7	25	133	202	765	3,305	4,754	4,336	4,104	674	18,305
Oct. 14	0	0	2	49	135	312	1,000	3,792	5,307	4,080	3,349	0	18,576
Oct. 21	0	0	0	2	14	35	218	958	1,691	1,425	1,461	0	6,804
Season.....	4	98	661	2,155	5,860	10,500	32,341	99,176	174,837	192,748	167,135	8,762	699,398

* Sizes smaller than 180 in 1938 and 1937 and smaller than 195 in 1938 and 1939 and odd sizes between 70 and 180 are not listed here separately but are included in the "total of all sizes."

Sources of data:
Data are from the same sources as table 18.

TABLE 20

SEASON'S AVERAGE AUCTION PRICES OF CALIFORNIA BARTLETT PEARS IN NEW YORK, CHICAGO, BOSTON, AND PHILADELPHIA, 1920-1940

Year	New York*	Chicago	Boston	Philadelphia
	<i>dollars per box</i>	<i>dollars per box</i>	<i>dollars per box</i>	<i>dollars per box</i>
1920.....	4.49	4.40	4.66	3.94
1921.....	3.51	3.51	3.46	3.39
1922.....	2.78	2.81	2.62	2.67
1923.....	3.05	2.87	3.02	2.90
1924.....	3.91	3.71	3.80	3.76
1925.....	2.83	2.78	2.68	2.71
1926.....	2.70	2.61	2.62	2.63
1927.....	3.33	3.37	3.21	3.34
1928.....	2.93	2.82	2.79	2.94
1929.....	3.69	3.59	3.44	3.55
1930.....	2.38	2.27	2.27	2.25
1931.....	2.67	2.56	2.52	2.57
1932.....	2.01	1.90	1.87	1.86
1933.....	2.31	2.29	2.27	2.29
1934.....	2.56	2.50	2.53	2.50
1935.....	2.37	2.35	2.32	2.31
1936.....	2.35	2.32	2.32	2.34
1937.....	2.48	2.42	2.44	2.47
1938.....	1.97	1.93	1.87	1.91
1939.....	2.56	2.51	2.51	2.51
1940.....	2.36	2.33	2.35	2.31

* Prices given in this table for New York in some years are slightly different from those given in table 13 because different agencies compiled the data and the weekly data in table 13 for some years are slightly less complete than the season's total as given above.

Sources of data:

The basic data on daily auction sales and prices are published in daily auction reports for each of the cities given, from which sources most of the data in this table were originally compiled by various agencies.

1920-1927: from annual data compiled by the California Fruit Exchange, except Boston in 1926: from Daily Fruit Auction Reports by Samuel J. Shallow Co., New England Distributors, Boston, Mass. (Mimeo.)

1928-1931: from California Pear Deals of California Federal-State Market News Service, annual issues, except Boston in 1928: from Daily Fruit Auction Reports, by Samuel J. Shallow Co., New England Distributors, Boston, Mass. (Mimeo.)

1932-1940: from same sources as table 21.

TABLE 21
VOLUME OF AUCTION SALES OF CALIFORNIA BARTLETT PEARS IN THE TWELVE AUCTION MARKETS, 1932-1940

Market	1932	1933	1934	1935	1936	1937	1938	1939	1940
New York.....	boxes 946,885	boxes 782,360	boxes 914,532	boxes 708,074	boxes 843,653	boxes 834,004	boxes 905,464	boxes 692,583	boxes 684,767
Chicago.....	292,675	278,959	273,039	235,939	279,819	327,499	290,116	253,149	259,523
Boston.....	188,610	132,016	208,465	157,367	206,741	215,124	214,901	189,105	200,539
Philadelphia.....	183,008	153,235	222,238	172,719	220,166	219,964	228,460	194,392	196,060
Pittsburgh.....	59,915	40,925	63,288	43,730	68,029	83,119	65,155	44,475	65,932
Cleveland.....	56,211	42,003	45,036	40,671	63,692	84,597	65,487	56,875	72,572
Baltimore.....	44,874	37,129	52,558	38,802	48,574	65,901	56,459	62,992	61,685
St. Louis.....	39,390	33,250	35,961	22,660	39,625	49,111	50,901	34,535	38,185
Cincinnati.....	30,233	27,928	35,881	27,215	39,384	48,254	49,989	38,505	45,493
Minneapolis.....	53,176	39,538	15,775	29,527	45,068	52,539	57,803	47,208	47,984
St. Paul.....	35,075	18,460	30,361	19,423	33,231	33,839	38,389	30,124	27,039
Detroit.....	59,852	39,799	62,555	47,999	75,480	70,149	55,291	37,888	48,236
Total.....	1,992,007	1,627,502	1,959,689	1,604,126	1,963,457	2,034,100	2,078,395	1,681,806	1,747,335

Sources of data:

1932-1936: compiled by Samsel, R. C. Weekly auction distribution of Bartlett pears, seasons 1932 to 1936, inclusive. U. S. Agricultural Adjustment Administration. p. 1-10. 1937. (Mimeo.)
 1937: compiled by Samsel, R. C. Sales and prices of California Bartlett pears at twelve markets, 1937 season. U. S. Agricultural Adjustment Administration. p. 6. January 7, 1938. (Mimeo.)
 1938: from York, George K. California pears, weighted-average prices received at eastern auction markets, 1938. California Federal-State Market News Service, Sacramento. p. 13. March, 1939. (Mimeo.)
 1939: from Cox, W. F., *et al.* Interstate shipments of California deciduous tree fruits, season of 1939. California Federal-State Market News Service, San Francisco. p. 62-64. April, 1940. (Mimeo.)
 1940: from York, George K. California pears, weighted-average prices received at eastern auction markets, 1940. California Federal-State Market News Service, Sacramento. p. 2. February, 1941. (Mimeo.)

TABLE 22
WEEKLY* AUCTION PRICES PER BOX OF CALIFORNIA BARTLETT PEARS
ON EIGHT MARKETS, 1935-1940

Week ending	Boston	New York†	Phila- delphia	Balti- more	Detroit	Cleve- land	Cincin- nati	Pitts- burgh
	dollars	dollars	dollars	dollars	dollars	dollars	dollars	dollars
1935:								
July 26.....	3.11	3.37	3.35	3.52	.....	.....	2.82	3.22
Aug. 2.....	2.76	2.88	2.84	2.76	2.45	2.49	2.37	2.68
9.....	2.27	2.19	2.12	2.09	2.30	2.11	2.10	2.11
16.....	2.21	2.37	2.18	2.21	2.12	2.25	1.94	2.01
23.....	2.52	2.43	2.36	2.61	2.36	2.33	2.48	2.24
30.....	2.44	2.50	2.48	2.60	2.26	2.43	2.24	2.37
Sept. 6.....	2.31	2.33	2.11	2.41	2.35	1.78	2.07	2.15
13.....	1.91	2.15	2.12	2.12	2.13	2.25	2.18	1.94
20.....	2.00	2.12	2.18	2.09	2.18	2.09	2.15	2.05
27.....	2.16	2.15	2.20	2.36	2.06	2.27	1.66	2.66
Oct. 4.....	2.25	2.58	2.52	2.57	2.69	2.62	1.58	2.48
11.....	2.56	2.71	2.78	2.64	2.76	2.27	1.58	2.44
1936:								
July 10.....	3.29	3.32	3.14	.....	2.75	2.56	2.62	2.83
17.....	2.69	2.37	2.68	2.59	2.45	2.48	2.20	2.50
24.....	2.29	2.24	2.27	2.21	2.15	2.19	2.27	2.16
31.....	1.73	1.83	1.84	1.69	1.80	1.89	1.88	1.82
Aug. 7.....	2.01	2.10	2.13	2.18	2.00	1.98	1.90	2.05
14.....	2.46	2.40	2.40	2.27	2.39	2.39	2.53	2.50
21.....	2.61	2.58	2.56	2.33	2.45	2.47	2.42	2.43
28.....	2.32	2.47	2.27	2.40	2.16	2.22	2.17	2.15
Sept. 4.....	2.16	2.27	2.17	2.05	2.16	2.30	2.05	2.12
11.....	2.29	2.44	2.27	2.18	2.25	2.33	1.97	2.19
18.....	2.62	2.51	2.42	2.44	2.66	2.47	2.59	2.68
25.....	2.79	2.80	2.89	2.94	2.60	.....	2.67	2.50
1937:								
July 24.....	3.65	3.58	3.41	3.17	3.07	3.19	2.85	3.04
31.....	2.55	2.47	2.46	2.33	2.34	2.34	2.49	2.55
Aug. 7.....	2.26	2.35	2.39	2.28	2.31	2.50	2.39	2.14
14.....	2.40	2.28	2.30	2.35	2.21	2.30	2.09	2.25
21.....	2.34	2.41	2.39	2.35	2.43	2.29	2.51	2.34
28.....	2.48	2.42	2.34	2.33	2.20	2.38	2.30	2.34
Sept. 4.....	2.38	2.55	2.47	2.36	2.27	2.37	2.29	2.26
11.....	2.50	2.66	2.67	2.32	2.49	2.65	2.61	2.39
18.....	2.31	2.46	2.39	2.37	2.39	2.43	2.44	2.45
25.....	2.13	2.26	2.26	2.45	2.30	2.46	2.24	2.35
Oct. 2.....	2.40	2.25	2.41	2.58	2.23	2.34	2.22	2.32
9.....	2.94	2.89	2.89	2.61	2.91	2.58	2.90	2.62
1938:								
July 23.....	2.78	2.52	2.12	2.41	2.29	2.14	2.66	2.52
30.....	2.08	1.94	2.08	2.13	1.96	1.97	1.90	2.02
Aug. 6.....	1.77	1.84	1.81	1.65	1.77	1.78	1.72	1.67
13.....	1.83	1.82	1.78	1.58	1.84	1.80	1.69	1.91
20.....	1.78	1.83	1.76	1.76	1.74	1.73	1.67	1.69
27.....	1.65	1.74	1.73	1.61	1.63	1.67	1.57	1.80
Sept. 3.....	1.59	1.76	1.61	1.44	1.73	1.67	1.59	1.57
10.....	2.13	2.32	2.02	1.78	1.97	2.11	2.25	1.72
17.....	1.95	2.09	2.11	2.17	1.93	2.09	2.16	2.19
24.....	1.80	2.04	2.04	2.18	2.09	1.91	1.79	1.96
Oct. 1.....	2.59	2.73	2.17	2.12	2.12	2.32	2.08	2.12
8.....	2.32	2.34	2.35	2.25	2.34	2.23	2.35	2.27

* For footnotes see p. 312.

(Concluded on page 312.)

TABLE 22—(Concluded)

Week ending	Boston	New York†	Phila- delphia	Balti- more	Detroit	Cleve- land	Cincin- nati	Pitts- burgh
	dollars	dollars	dollars	dollars	dollars	dollars	dollars	dollars
1939:								
July 15.....	3.34	3.27	2.94	3.07	2.41	2.64	2.66	2.99
22.....	2.39	2.46	2.39	2.71	2.31	2.33	2.32	2.27
29.....	2.37	2.32	2.35	2.28	2.28	2.43	2.08	2.30
Aug. 5.....	2.34	2.51	2.30	2.19	2.50	2.20	2.33	2.29
12.....	2.71	2.63	2.65	2.43	2.49	2.55	2.61	2.45
19.....	2.66	2.71	2.78	2.65	2.47	2.50	2.51	2.64
26.....	2.64	2.57	2.51	2.60	2.52	2.51	2.44	2.54
Sept. 2.....	2.30	2.51	2.40	2.53	2.52	2.42	2.54	2.14
9.....	2.73	2.59	2.54	2.64	2.31	2.41	2.59	2.47
16.....	2.43	2.58	2.59	2.71	2.26	2.61	2.57	2.53
23.....	2.68	2.73	2.65	2.73	2.44	2.45	2.44	2.66
30.....	2.33	2.43	2.59	2.58	2.50	2.25	2.28	2.68
1940:								
July 13.....	2.91	2.90	2.59	3.18	2.42	2.68	3.15	2.58
20.....	2.72	2.75	2.76	2.46	2.67	2.39	2.37	2.72
27.....	2.56	2.53	2.46	1.93	2.35	2.54	2.13	2.48
Aug. 3.....	2.35	2.17	2.15	2.14	1.92	2.07	2.16	2.00
10.....	2.07	2.30	2.08	2.16	2.22	1.92	1.87	2.10
17.....	2.48	2.29	2.07	1.94	2.05	2.19	2.30	2.17
24.....	2.17	2.12	2.18	1.92	2.30	2.16	2.01	1.99
31.....	2.18	2.34	2.33	2.24	2.05	2.28	2.08	2.16
Sept. 7.....	2.62	2.51	2.58	2.41	2.32	2.33	2.44	2.36
14.....	2.32	2.38	2.30	2.40	2.39	2.36	2.23	2.31
21.....	2.28	2.20	2.19	2.17	2.17	2.22	2.02	2.04
28.....	2.26	2.41	2.32	2.20	2.36	2.34	2.20	1.88

* Does not include all the weeks of the season but only the twelve important sales weeks designated as weeks 1-12 in table 13.

† Data for New York in 1935, 1936, and 1938 do not always check with data in table 13 because different agencies compiled the data.

Sources of data:

* Data from same sources as table 21.

TABLE 23
ANALYSIS OF VARIANCE OF WEEKLY PRICES OF CALIFORNIA BARTLETT PEARS
ON TWO GROUPS OF FOUR AUCTION MARKETS, 1935-1938

	Boston, New York, Philadelphia, and Baltimore			Detroit, Cleveland, Cincinnati, and Pittsburgh		
	Degrees of freedom	Sum of squares	Mean square	Degrees of freedom	Sum of squares	Mean square
	1935					
Source of variation:						
Total.....	43	2.6345	.....	43	3.2285	.....
Between means of markets.....	3	0.0689	0.0230	3	0.5924	0.1975
Between means of weeks.....	10	2.3025	0.2302	10	0.7437	0.0744
Remainder, interaction.....	30	0.2631	0.0088	30	1.8924	0.0631
Ratio of variance.....	$F = \frac{0.0230}{0.0088} = 2.61^*$			$F = \frac{0.1975}{0.0631} = 3.13^*$		
	1936					
Source of variation:						
Total.....	43	3.5007	.....	39	2.1586	.....
Between means of markets.....	3	0.0321	0.0107	3	0.0317	0.0106
Between means of weeks.....	10	3.2077	0.3208	9	1.9213	0.2135
Remainder, interaction.....	30	0.2609	0.0087	27	0.2056	0.0076
Ratio of variance.....	$F = \frac{0.0107}{0.0087} = 1.23^*$			$F = \frac{0.0106}{0.0076} = 1.39\dagger$		
	1937					
Source of variation:						
Total.....	43	1.2616	.....	43	1.2408	.....
Between means of markets.....	3	0.0265	0.0088	3	0.0255	0.0085
Between means of weeks.....	10	0.9086	0.0909	10	0.8846	0.0885
Remainder, interaction.....	30	0.3265	0.0109	30	0.3307	0.0110
Ratio of variance.....	$F = \frac{0.0109}{0.0088} = 1.24\dagger$			$F = \frac{0.0110}{0.0085} = 1.29\dagger$		
	1938					
Source of variation:						
Total.....	43	2.7989	.....	43	2.4215	.....
Between means of markets.....	3	0.0701	0.0234	3	0.0254	0.0085
Between means of weeks.....	10	2.2704	0.2270	10	2.0599	0.2060
Remainder, interaction.....	30	0.4584	0.0153	30	0.3362	0.0112
Ratio of variance.....	$F = \frac{0.0234}{0.0153} = 1.53^*$			$F = \frac{0.0112}{0.0085} = 1.32\dagger$		

* $F = 2.92$ at the 5 per cent point, and $F = 4.51$ at the 1 per cent point, for (3 corresponding to the greater mean square) and 30 degrees of freedom.

† $F = 2.96$ at the 5 per cent point, and $F = 4.60$ at the 1 per cent point, for 3 (corresponding to the greater mean square) and 27 degrees of freedom.

‡ $F = 8.62$ at the 5 per cent point, and $F = 26.50$ at the 1 per cent point, for 30 (corresponding to the greater mean square) and 3 degrees of freedom.

Source of data:

Based upon data in table 22.

TABLE 24

FREIGHT AND REFRIGERATION RATES ON DECIDUOUS FRUITS FROM CALIFORNIA
SHIPPING POINTS TO TWELVE MARKETS AS OF JUNE, 1940

Destination	Freight rates		Refrigeration charges under different icing rules*						
	Minimum carload		Stand- ard	Rule 240	Rule 247		Rule 254		
	27,500 pounds	34,000 pounds			Iced by shipper	Iced by carrier	Not re-iced	Re-iced once	Re-iced twice
	<i>dollars per 100 pounds</i>	<i>dollars per 100 pounds</i>	<i>dollars per carload</i>	<i>dollars per carload</i>	<i>dollars per carload</i>	<i>dollars per carload</i>	<i>dollars per carload</i>	<i>dollars per carload</i>	
Boston.....	1.63	1.50	97.50	16.00	31.00	50.00	41.50	55.00	75.00
New York.....	1.63	1.50	95.00	15.00	30.00	49.00	40.50	54.00	74.00
Philadelphia.....	1.63	1.50	95.00	15.00	30.00	49.00	40.50	54.00	74.00
Baltimore.....	1.63	1.50	95.00	15.00	30.00	49.00	40.50	54.00	74.00
Pittsburgh.....	1.63	1.50	85.00	14.00	29.00	48.00	39.50	53.00	73.00
Cincinnati.....	1.63	1.50	85.00	14.00	29.00	48.00	39.50	53.00	73.00
Detroit.....	1.63	1.50	85.00	14.00	29.00	48.00	39.50	53.00	73.00
Cleveland.....	1.63	1.50	85.00	14.00	29.00	48.00	39.50	53.00	73.00
Chicago.....	1.63†	1.50	79.00	12.00	27.00	46.00	37.50	51.00	70.00
St. Louis.....	1.63†	1.50	79.00	12.00	27.00	46.00	37.50	51.00	70.00
Minneapolis.....	1.63†	1.50	79.00	12.00	27.00	46.00	37.50	51.00	70.00
St. Paul.....	1.63†	1.50	79.00	12.00	27.00	46.00	37.50	51.00	70.00

* The different methods of refrigeration, or icing rules, for which different refrigeration rates are charged by the railroads are as follows:

Standard refrigeration (pre-iced or dry-car loaded).

Rule 240, initially iced by shipper, or if by carrier cost of ice is in addition to charges shown; not re-iced by carrier.

Rule 247, initially iced by shipper; re-iced once in transit by carrier; or initially iced by carrier; re-iced once in transit by carrier.

Rule 254, pre-iced and replenished by carrier; not re-iced; or pre-iced and replenished by carrier; re-iced once in transit; or pre-iced and replenished by carrier; re-iced twice in transit.

† A minimum carload weight of 26,000 pounds to Chicago, St. Louis, Minneapolis, and St. Paul takes the freight rate of \$1.63 per 100 pounds.

Source of data:

California Fruit Exchange, Traffic Department Circular No. 258, Sacramento, California, p. 1-7. June 11, 1940. (Mimeo.)

TABLE 25

NEW YORK WHOLESALE PRICES OF FRESH ORANGES, PLUMS, PEACHES, AND PEARS,
AVERAGE JULY-AUGUST; AND NEW YORK STATE FACTORY WAGES,
AVERAGE JUNE-AUGUST, 1924-1939

Year	Oranges	Plums	Peaches	Pears	Wage per week
	1	2	3	4	5
	dollars per 100 pounds*	dollars per 100 pounds*	dollars per 100 pounds*	dollars per 100 pounds*	dollars
1924.....	6 63	8 86	4 96	8 04	27 22
1925.....	9 10	7 27	4 87	5 67	28 03
1926.....	7 20	6 68	3 35	5 44	28 89
1927.....	8 63	8 09	5 70	7 15	29 14
1928.....	10 71	7 41	4 13	5 81	29 34
1929.....	6 36	10 86	6 70	7 60	29 97
1930.....	10 50	6 23	6 35	5 06	28 68
1931.....	5 81	6 86	3 91	5 40	26 35
1932.....	4 71	6 09	4 57	4 06	21 98
1933.....	4 60	5 86	3 57	4 78	22 26
1934.....	5 73	6 36	4 74	5 04	23 26
1935.....	4 96	7 00	4 61	4 94	24 16
1936.....	5 87	6 36	5 35	4 56	25 35
1937.....	7 67	7 95	5 35	4 98	27 97
1938.....	4 61	5 70	4 28	3 70	26 07
1939.....	4 59	6 55	4 04†	5 12	27 22

* Converted to dollars per 100 pounds from prices of oranges in 70-pound box; plums for 1924-1937 in 22-pound crate and for 1938-1939 in 234-pound crate; peaches in 46-pound 6-basket carrier; and pears for 1924-1932 in 48-pound box and for 1933-1939 in 50-pound box.

† Preliminary estimate.

Sources of data:

Cols. 1, 2, and 4: New York auction prices of California Bartletts, of California plums (most important varieties), and of California Valencia oranges compiled by various agencies from the *New York Daily Fruit Reporter*.

Col. 3: The average wholesale less-than-curland-lot prices of all peaches sold on the New York market in 6-basket carriers as compiled by the United States Department of Agriculture, Agricultural Statistics, and current mimeographed reports of the United States Bureau of Agricultural Economics, *The Fruit Situation*.

Col. 4: The New York state factory wages are simple averages of the average weekly wage for June, July, and August.

1924-1935: from United States Bureau of Labor Statistics. *Handbook of labor statistics*. p. 831. 1936.

1936-1939: from New York State Industrial Commissioner. Department of Labor. *The Industrial Bulletin*, April, 1941, issue.

TABLE 26
NEW YORK UNLOADS* OF FRESH ORANGES, PEACHES, PEARS, AND PLUMS,
JULY-AUGUST, 1924-1940

Year	Oranges	Peaches	Pears	Plums
	<i>tons</i>	<i>tons</i>	<i>tons</i>	<i>tons</i>
Annual:				
1924.....	21,258	41,830	18,489	6,582
1925.....	18,426	38,772	21,919	5,526
1926.....	24,762	46,516	29,328	5,742
1927.....	22,766	32,500	17,082	5,758
1928.....	18,766	46,820	20,708	6,000
1929.....	35,702	36,990	13,071	3,504
1930.....	23,718	29,680	22,068	7,998
1931.....	39,263	50,940	19,255	5,638
1932.....	38,553	27,642	17,293	7,364
1933.....	36,640	35,560	11,063	8,136
1934.....	34,022	29,762	18,552	6,955
1935.....	36,817	37,338	9,605	6,807
1936.....	34,201	31,906	14,161	6,576
1937.....	28,302	27,574	11,890	12,298
1938.....	40,091	38,668	14,289	12,384
1939.....	47,712	35,980	12,728	14,220
1940.....	37,663	38,746	12,446	15,298
Averages:				
1924-1928.....	20,596	41,288	21,505	5,922
1929-1933.....	34,755	36,162	16,550	6,528
1934-1938.....	34,687	33,050	13,693	9,004

* Includes only rail and boat unloads prior to July 15, 1928, but also includes truck unloads beginning July 15, 1928.

Source of data:

From United States Bureau of Agricultural Economics. Unloads of fruits and vegetables at New York city, annual reports. (Mimeo.) Data reported in carlot equivalents and converted to tons at various factors, according to the fruit and state of origin.

TABLE 27
SUPPLIES AND AUCTION PRICES OF PACIFIC COAST FRESH BARTLETT PEARS, AND UNITED STATES INDEX OF
NONAGRICULTURAL INCOME, 1925-1940

Year	Volume of supplies					Auction price* per box			United States index of nonagricultural income July-October†
	California		Oregon and Washington			California Bartletts		Oregon and Washington Bartletts	
	All pear varie- ties, interstate shipments during Bartlett season‡	Bartletts shipped fresh out of state‡	Bartletts‡ sold at seven auction markets	All pear varie- ties, shipments during Cali- fornia Bartlett season‡	Bartletts used fresh	Actual	Calculated		
	1,000 short tons	1,000 short tons	1,000 short tons	1,000 short tons	1,000 short tons			dollars	
1925	83	77	49	39	46	2.78	3.11	2.99	98
1926	105	101	65	48	71	2.65	2.77	2.40	100
1927	88	79	55	30	41	3.31	3.27	3.21	102
1928	101	94	55	63	56	2.86	2.58	2.75	105
1929	82	78	46	32	39	3.61	3.42	3.52	109
1930	120	116	63	52	55	2.31	2.27	1.78	97
1931	84	88	50	23	44	2.61	2.62	2.67	83
1932	66	67	42	20	37	1.94	2.15	1.74	64
1933	52	52	36	25	48	2.30	2.12	1.97	64
1934	72	79	44	34	34	2.53	2.26	2.45	71
1935	63	54	36	33	38	2.35	2.33	2.19	78
1936	68	72	42	42	56	2.33	2.39	2.35	89
1937	79	80	44	36	34	2.45	2.52	2.27	95
1938	89	83	45	40	40	1.93	2.05	1.93	87
1939	67	66	36	36	43	2.53	2.46	2.14	93
1940	68	64	37	44	52	2.33	2.45	2.16	99

* Prices are for California Bartletts in seven auction markets and Oregon and Washington Bartletts on the New York auction market.

† The length of the California Bartlett season as used in columns 1 and 4 is through the last chief week of California Bartlett sales on the New York auction market, usually the twelfth or thirteenth marketing week as designated by an asterisk as the last week in table 13. California interstate rail and Oregon and Washington total rail shipments for 1925-1935 allow two weeks' time between shipment date and date of sale in New York, and for 1936-1940 allow 11 days. Three weeks have been allowed for intercoastal-boat shipments from California. California shipments are interstate by rail plus small amount by intercoastal steamer in 1925-1940.

‡ Bartletts shipped fresh out of California include direct exports as well as interstate rail and water shipments.

§ Quantity in boxes converted to tons at 48 pounds per box in 1925-1932 and 50 pounds per box in 1933-1940.

|| Index based on calendar years; excludes bonus payments to veterans in 1931 and 1936.

¶ Preliminary.

(Table concluded on p. 318.)

(For table 27 to which these data refer, see p. 317.)

Sources of data:

- Col. 1: From Federal-State Market News Service, San Francisco. Daily and annual reports on interstate shipments of California deciduous-tree fruits. Converted from cars at following tons per car: 1925-1932, 12; 1933, 12½; 1934-1936, 13; 1937, 16; and 1938-1940, 17.
- Col. 2: From California Cooperative Crop Reporting Service, except 1940 which is a preliminary estimate.
- Col. 3: Data are the quantity of auction sales of all California Bartlett's in seven auction markets—New York, Chicago, Boston, Philadelphia, Pittsburgh, St. Louis, and Cincinnati, 1925-1940; from same source as tables 20 and 21, except Pittsburgh in 1926 from daily mimeographed compilations by S. M. Young, Broker Distributor, Auction Sales, Pittsburgh, and St. Louis in 1926 from St. Louis Distributing Co., St. Louis *Daily Market Reporter*, and Cincinnati in 1926 and 1928 from mimeographed releases of United States Market News Service, Fruit Auction Sales, Cincinnati, Ohio.
- Col. 4: 1925-1927: United States Bureau of Agricultural Economics. Weekly summaries of carlot shipments. (Mimeo.)
- Col. 5: 1928-1940: data exclude shipments to manufacturers and hence were compiled from current daily Federal-State Market News Service, San Francisco, reports on interstate shipments of California deciduous-tree fruits. Converted from cars to tons, same as in col. 1.
- Col. 6: Harvested production of Bartlett's as reported by the United States Crop Reporting Service, converted to tons at 50 pounds per bushel, minus tonnage of pears used for canning, from data of Northwest Cannery Association, Crop Reporting Service, Portland, Oregon, and the trade.
- Col. 7: Prices are for auction sales of all California Bartlett's in seven auction markets—New York, Chicago, Boston, Philadelphia, Pittsburgh, St. Louis, and Cincinnati. From same source as col. 3.
- Col. 8: Data calculated from table 9, equation 5 (p. 290).
- Col. 9: Weighted-average prices of Oregon and Washington Bartlett's on the New York auction market, 1925 and 1937-1940; compiled from daily issues of the *New York Daily Fruit Reporter*; 1926-1936; compiled by United States Bureau of Agricultural Economics Division of Statistical and Historical Research, from daily auction sales reports.
- Col. 10: Simple average of monthly data.
- July, 1925-July, 1940: from United States Bureau of Agricultural Economics. Mimeographed release of September 3, 1940.
- August-October, 1940: from United States Department of Commerce, Survey of Current Business, monthly issues.

TABLE 28
GROSS RETURNS FROM CALIFORNIA BARTLETT PEARS ON SEVEN*
MAJOR AUCTION MARKETS, 1924-1940

Season	Gross returns	
	Absolute	Percentages, 1924-1929 = 100
	1	2
	<i>dollars</i>	<i>per cent</i>
1924.....	5,997,450	90.5
1925.....	5,680,256	85.7
1926.....	7,134,549	107.6
1927.....	7,544,323	113.8
1928.....	6,575,414	99.2
1929.....	6,846,353	103.3
1930.....	6,080,105	91.7
1931.....	5,408,973	81.6
1932.....	3,389,378	51.1
1933.....	3,331,736	50.3
1934.....	4,435,091	66.9
1935.....	3,350,365	50.5
1936.....	3,951,236	59.6
1937.....	4,359,251	65.8
1938.....	3,486,827	52.6
1939.....	3,655,055	55.1
1940.....	3,468,826	52.3

* The seven markets are New York, Chicago, Boston, Philadelphia, Pittsburgh, St. Louis, and Cincinnati.

Sources of data:

Col. 1: Summation of gross returns from the seven markets based on season's prices and total sales as given in same sources as for tables 20 and 27, col. 3.

Col. 2: Calculated from data in col. 1.

THE RELATION OF MATURITY OF THE
GRAPES TO THE YIELD, COMPOSITION,
AND QUALITY OF RAISINS¹H. E. JACOB²

THAT THE MATURITY of grapes is related to the yield and quality of the raisins made from them has probably been observed almost as long as grapes have been dried to preserve them. Apparently, however, no one attempted to determine precisely the nature and magnitude of these relationships before the work done by Bioletti (1915),³ which was begun about 1913. Important contributions have since been made by Lyon (1920, 1924), Cruess and Christie (1921), and Nichols and Christie (1930).

Bioletti (1915) reports on tests made with Muscat of Alexandria and Sultanina (Thompson Seedless) at Kearney Park, near Fresno, and at Davis, during the seasons of 1913 and 1914. With Muscat, the drying ratios reported ranged from 4.8 for grapes of 18° Balling to 3.1 for grapes of 28° Balling. Quality, as measured by the size of the individual raisins, improved notably as maturity advanced. With Sultanina, the drying ratios ranged from 4.6 for grapes of 20° Balling to 3.6 for grapes of 24° Balling. According to Bioletti's calculations, the average increase in crop per Balling degree of sugar in the grapes was about 5.35 per cent with Muscat and 7.4 per cent with Sultanina. In another paper Bioletti (1919) briefly reported, collectively, on the results of several years' tests on the drying of eleven varieties of grapes. He interpreted his results as showing an average increase of 35 pounds of dried grapes per ton of fresh for each added degree of sugar. Actually, his figures show the increase to range from 16 to 104 pounds, the greater increases being obtained from the riper fruit. Although he recognized that the higher sugar content measured in the fresh fruit with advancing maturity is chiefly responsible for the increased yield, he was led by his earlier ex-

¹ Received for publication April 16, 1941.

² Associate in Viticulture and Associate in the Experiment Station.

³ See "Literature Cited" for complete data on citations, referred to in the text by author and date of publication.

periments to believe that something other than sugar must be a factor in producing the larger increases as maturity became advanced. Lyon's (1920) figures for "Sultana" and "Zante currant" raisins also fluctuate between rather wide limits, but fail to show any consistent trend toward greater increases in yield of raisins per degree Balling as the maturity of the fresh fruit advanced.

In 1926, Bioletti began a more elaborate investigation in collaboration with Christie⁴ and the present author. The work has been continued down to the present time, and this paper will present the principal results.⁵

SOURCES OF THE FRUIT

During the 1926 season, lots of grapes were picked at weekly intervals, August 22 to October 17 inclusive, from about thirty vines in a vineyard near Marysville. For the 1927, 1935, and 1936 series of tests, all fruit was obtained from the University of California vineyards at Davis. Each season, except 1926, two adjacent rows of twenty vines each were chosen as sources of the fruit, one row having been thinned to a light-to-moderate crop, the other being permitted to bear a moderate-to-heavy crop. Pickings were made at approximately weekly intervals, beginning when the fruit was relatively green (for raisins) and extending to the end of the season, when fruit in good physical condition could no longer be obtained. In general, only one large or two medium-sized clusters were harvested from each vine at each picking; and all those from one lot of vines were combined to form a composite sample of 18 kilograms or more.

PREPARATION OF THE SAMPLES FOR DRYING

Except the natural sun-dried lots of 1926 and 1927, all samples were prepared as follows: The individual berries were clipped from the clusters by cutting the pedicels with scissors. All dried, injured, or discolored berries were discarded. The lot was then thoroughly mixed by repeated gentle pouring from one container to another; in this procedure, metal cans of about 3½ cubic feet capacity were found convenient. After the mixing, a small part of the lot was taken out for the observations and measurements on the fresh fruit; and from the remainder, samples of 1,500 or 2,000 grams each were weighed out for the individual drying tests.

For the natural sun-drying tests in 1926 and 1927, entire clusters were used; the individual lots varied in fresh weight from 7 to 15 kilograms.

⁴ A. W. Christie, Assistant Professor of Fruit Products and Associate Chemist in the Experiment Station, University of California; resigned 1928.

⁵ Some of the data obtained in 1926 were published by Nichols and Christie (1930).

Samples for measurements on the fresh fruit were obtained by clipping off a few berries from the basal, middle, and apical portions of each cluster.

MEASUREMENTS ON THE FRESH FRUIT

Weight of One Hundred Berries.—The berry weight was determined by counting out and weighing single lots of 1,000 berries in 1926; single lots of 500 in 1927; and duplicate, triplicate, or quadruplicate lots of 200 each in 1935 and 1936. This last procedure proved to be the most reliable; if the weights of the duplicate lots failed to agree within reasonable limits, additional lots were counted, weighed, and included in the computation. In each case, the results were calculated to weight per 100 berries.

Balling.—Part of the composite sample was thoroughly macerated in a pan by means of a wooden masher or by passing it through a continuous screw-press, and the juice was extracted from the macerated pulp by squeezing or straining through cheesecloth. The juice was poured into glass jars, where it was allowed to stand for a few minutes to permit the escape of air bubbles and settling of the gross sediment. Balling (or Brix) hydrometers, graduated in $\frac{1}{10}$ degrees, were used in glass cylinders of appropriate size. All determinations were made in duplicate or triplicate, and the readings corrected for temperature differences.

Acidity.—The juice extracted for the Balling test was allowed to stand until part of it had become reasonably clear, but never for more than an hour. Duplicate 10-cc portions of the clear juice were then titrated with standardized NaOH solution, phenolphthalein serving as an indicator. A faint color, lasting 10 seconds or longer with constant shaking, was taken as the end point. The results were calculated and expressed as per cent tartaric acid by weight.

METHODS OF DRYING

During the investigation, standard commercial methods of pretreatment and drying were employed; and, in addition, the standard methods were duplicated with either dehydrated or naturally dried lots. The various methods used are briefly described below; the years in which the method was used are indicated.

(1) Natural sun-drying, in 1926, 1927, 1935, and 1936: The grapes were thinly spread, without pretreatment, on trays and exposed to direct solar radiation until dried to the desired degree. In 1926 and 1927, standard wood raisin trays (2×3 feet) were used, and the raisins dried in the open. Since, however, losses were caused by bees and birds, a large cage of $\frac{3}{16}$ -inch mesh hardware cloth was used in 1935 and 1936, and the raisins were dried on paper-covered laboratory-dehydrater trays

inside the cage. The losses were thus practically eliminated. The product was similar to the natural sun-dried raisins of commerce.

(2) Dehydration without pretreatment, in 1926, 1927, 1935, and 1936: The sample was spread on a paper-lined tray, without pretreatment, and dehydrated in a laboratory dehydrator of the recirculating tunnel type, electrically heated and thermostatically controlled to a minimum of 130° F and a maximum of 140°. The rate of air flow exceeded 600 lineal feet per minute between the trays. Humidity, although kept low, was not controlled within close limits. As the desired degree of dryness in the raisins was approached, the trays were weighed at 1- or 2-hour intervals. The end point in drying was determined by assuming a water content of 15 per cent in the dried raisins and by assuming that the Balling reading on the juice of the fresh grapes would indicate the total solids of the grapes. Then the constant 85 (100 minus 15) divided by the Balling of the fresh grapes approximates the drying ratio. The weight of fresh fruit divided by the drying ratio is the calculated weight of the raisins, which was taken as the end point of the drying. The raisins were uniform grayish brown in color, rather tough-textured, and slightly caramelized to the taste.

(3) Lye dip with dehydration, in 1926 and 1935: The grapes were dipped in a 0.2 to 0.3 per cent NaOH solution at a temperature of 95° to 100° C for 2 or 3 seconds—until faint checks showed in the skins after the grapes had been cooled by rinsing in cold water. The sample was then dehydrated as for (2). The raisins were uniform medium brown in color, and otherwise resembled the commercial product occasionally made in this manner.

(4) Lye dip with sun-drying, in 1935: The sample was dipped as for (3) and sun-dried as for (1). The raisins were dark brown, tender, meaty, and slightly sticky—generally similar to the commercial product occasionally made by this process.

(5) Golden bleach, in 1935 and 1936: The hot lye dipping as for (3) was followed by exposure at ordinary air temperature to SO₂ gas (diluted to about 1 per cent by weight with air) until the grapes had bleached to a yellowish white, the fruit absorbing 1,200 to 2,000 p.p.m. of SO₂. They were then dehydrated as in (2). In these experiments the procedure differed in two minor respects from the standard commercial process: first, the SO₂ for bleaching the grapes was derived from the commercial liquefied product instead of from burning sulfur; second, the dehydration temperature was lower, since commercial dehydrators usually operate at about 160° F. The product was of brilliant, glossy, greenish-yellow to golden-yellow color.

(6) Sulfur bleach, in 1935 and 1936: The grapes were treated as for

(5), then exposed to direct sunlight until half or two-thirds dried. The drying was finished in the shade. Exposure to direct sunlight was for a longer period than is usual in commercial practice. Except in being a pronounced reddish-yellow, the raisins were similar to the commercial product.

(7) Australian mixed dip with dehydration, in 1935: The dip was composed of 0.3 per cent NaOH, 0.5 per cent K_2CO_3 , and 0.4 per cent virgin olive oil, this last being first emulsified in a 5 per cent K_2CO_3 solution. It was used at 80° – 82° C, and the grapes were immersed until faint checks showed in the skin after cooling without rinsing—a matter of 2 or 3 seconds. Dehydration was as described for (2). The raisins resembled those of (3) in color, but were more glossy; the texture was more tender than with those of (3). The process is not used commercially.

(8) Australian mixed dip with rack-drying, in 1935 and 1936: The predrying treatment was as for (7). The grapes were dried in the shade on specially constructed wire racks like those commonly used in Australian drying yards. The dip and the drying procedure were essentially the same as described by Lyon (1934). The day after the grapes were placed on the racks, and thereafter at weekly intervals until dry, they were lightly sprayed with a 5 per cent solution of K_2CO_3 in which 0.4 per cent olive oil had been emulsified. The raisins were of soft, tender texture, of characteristic flavor; and the color varied from light to dark brown, the darker colors developing in samples subjected to foggy or rainy weather at some time during the drying period.

(9) Australian cold dip with dehydration, in 1935: The dip was composed of a 5 per cent solution of K_2CO_3 (technical grade) in which was emulsified 0.4 per cent virgin olive oil. It was used at about 35° C, and the grapes were immersed until about three fourths of the bloom had been removed—usually 1 to 4 minutes. The drying was as for (2), and the dried product resembled that of (7). This process is not used commercially.

(10) Australian cold dip with rack-drying, in 1935 and 1936: The predrying treatment was as for (9), and the drying as for (8). The composition of the dip and the drying procedure were essentially the same as that recommended by de Castella (1925). The product varied from light greenish brown to medium brown and in other respects resembled that of (8), but had somewhat better texture. This and (8) are the processes used in making the "Sultana" raisins of Australia and South Africa.

(11) California soda-oil dip with dehydration, in 1935: The dip consisted of a 4 per cent water solution of Wyandotte (soda ash) powder on which was floated a thin film of olive oil. It was used at about 35° C.

The grapes were immersed until about three fourths of the bloom had been removed—usually 30 to 60 seconds. They were dehydrated as for (2). The dried product resembled that of (7). This process is not used commercially.

(12) California soda-oil dip with sun-drying, in 1935: The predrying treatment was as for (11), the drying as for (1). The process was once used extensively in the Sacramento Valley, but now has been largely abandoned. The raisins were medium brown and otherwise resembled the commercial product.

OBSERVATIONS AND DETERMINATIONS ON THE RAISINS*

Immediately after the final weighing of the dried raisins, part or all of each lot was packed into a glass preserving jar, sealed, stored for a few days at room temperature, and then held at 1° C until used.

The physical measurements attempted were based largely on the report of Chace and Church (1927) except that moisture was determined by direct vacuum-oven drying. The chemical determinations followed standard practices wherever possible, the methods of the Association of Official Agricultural Chemists (1935) being used as guides.

Drying Ratio.—After the moisture determinations, the dry weight of each lot was adjusted by calculation to a 15 per cent moisture basis. The drying ratio was then calculated by dividing the original fresh weight by the dry weight adjusted to a basis of 15 per cent moisture. Usually, in the tables and discussion following, the quotient only is expressed. The ratio is, however, always implied.

Weight of Raisin Berries.—The sample was loosened up to separate the individual raisin berries from each other, then mixed by slowly rotating the partially filled jar in an end-over-end manner. Duplicate lots of 200 berries each were counted out and weighed. If the weights of the two lots differed by more than 5 per cent, additional lots were taken. The weight of 100 raisin berries was calculated from the total number counted and from their total weight.

Weight per Unit Volume.—The laboratory method of Chace and Church (1927) for this measurement was modified by the use of a home-made mechanical shaker. A calibrated 500-cc wide-mouth Erlenmeyer flask was filled to overflowing with loose raisins. The flask was then placed in a receptacle on the shaker, which was so constructed as to provide an abrupt vertical drop of about $\frac{1}{4}$ inch at the rate of 120 times per minute. The shaker was run for $1\frac{1}{2}$ minutes with each sample. The flask was large enough so that when the shaking was finished most of the

* Most of the routine work of chemical analysis on the 1935 and 1936 raisin samples was done by Bernard A. Fries.

samples slightly overran the 500-cc volume mark. The volume was adjusted to the mark by removing or adding a few raisins as necessary. All determinations were made in duplicate; and the duplicates checked, in all but occasional instances, within 2 per cent of each other. Where greater differences occurred, the determinations were repeated. Satisfactory checks could not be obtained by hand-shaking nor on the mechanical shaker with less than 1½ minutes' shaking. The weights obtained for 500 cc are heavier than those reported by Chace and Church.

Mold and Fermentation.—The hydrogen peroxide test described by Chace and Church (1927) for mold and fermentation was used on a sample of 100 raisin berries from each lot. Since the amount of mold and decay observed appeared to be correlated only with weather conditions during drying and with the method of drying, not with the maturity of the grapes, the data are not reported; but lots in which more than 10 per cent of the berries showed evidence of mold or yeast growth were discarded.

Moisture in the Raisins.—A portion of 250 grams or more of the original raisin sample was passed four times through a small household-type food chopper with a nut-butter attachment. The ground sample was then sealed in a glass sample jar, and from it portions were withdrawn for all determinations requiring ground material.

The moisture test was made as follows: Filter papers of 9-cm size were oven-dried at 80° C for 8 hours, cooled in a desiccator over soda lime, and weighed in a tared, closed petri dish. About 5 grams of the ground raisin pulp was quickly and thinly spread by means of a spatula on the paper, which was rested on a glass plate; then the paper, now holding the sample, was again weighed in the petri dish. The operations of placing the sample on the paper and replacing the paper in the petri dish were performed as quickly as possible in order to minimize changes in weight due to moisture absorption or loss. The drying was done in a vacuum oven at 70° C for 12 hours, under a pressure approximating 100 mm mercury, with a slow current of dried air passing through the oven. The dried samples, cooled in a desiccator over soda lime, were finally weighed in the closed petri dish. Determinations were in duplicate. In comparisons made during the preliminary work, the method yielded more consistent results with much less labor than the Association of Official Agricultural Chemists' official method (1935) making use of asbestos. The end point was essentially the same as that obtained by using the official procedure and drying for 10 hours. Consistent results could not be obtained by the official method with only 6 hours' drying.

Sugar Content of the Raisins.—Determinations of sugars on the 1926 samples (by the Fruit Products Laboratory at Berkeley) were made as

follows: A 10-gram portion of the ground sample was extracted by boiling in 500 cc water, filtered, then cleared with Horne's basic lead acetate and sodium oxalate. Copper oxide precipitated by the regular Munson and Walker procedure was determined by the Shaeffer-Hartman (1920) method. With the 1927 samples, 5 grams of raisins were extracted with 95 per cent alcohol in Soxhlet apparatus. The extract, brought to sirupy consistency under reduced pressure, was taken up in water, and the determination made thenceforth as with the 1926 samples. The results were less consistent than was desired.

With the 1935 and 1936 samples, the determination of total water-insoluble matter was included, and the following procedure of extraction gave satisfactory results: Filter papers, 15 cm in diameter, were dried and weighed as for the moisture determinations. Before drying, the paper was folded to make a roughly conical receptacle that could be inserted in a Soxhlet extraction tube with the top edge above the high point in the siphon. About 10 grams of the ground raisin pulp was smeared on the inside of the paper cone and weighed, then placed in the extraction tube so that the drip from the condenser fell directly into the paper cone containing the sample. Extraction was with water for 6 to 8 hours, the water in the boiling flask being changed two or three times early in the extraction period to avoid "bumping" and partial caramelization of the sugars on the sides of the flask. The several extract portions were combined and made up to 1-liter volume.

An aliquot portion of the extract to be used for the sugar determination was cleared in the usual manner with lead acetate and sodium oxalate. Copper oxide precipitated by the Quisumbing and Thomas method (Association of Official Agricultural Chemists, 1935) was determined by direct weighing. Very close agreement was obtained from determinations on duplicated samples.

Since preliminary tests showed no sucrose to be present, only reducing sugars were determined.

Water-Insoluble Solids in the Raisins.—The residue in the filter paper, after the extraction described above for the 1935 and 1936 samples, was dried at 80° C for 8 hours, cooled in a desiccator, and weighed in a closed petri dish.

Titrateable Acid in the Raisins.—The total titrateable acidity was determined by titrating 100-cc portions of the extract (made up to 1-liter volume) with 0.033 *N* sodium hydroxide, phenolphthalein serving as the indicator. If the end point was obscured by the brown color of the extract, a spot plate was used.

Potassium, Calcium, Magnesium, and Phosphorus Content.—A 10-gram sample of the ground raisins was charred in a porcelain crucible

over the free flame of a Bunsen burner. About 1 cc of dilute H_2SO_4 was added to the charred mass, which was then ashed at 580°C . Silica was removed by twice evaporating with 1 to 5 HCl . The ash was then dissolved in additional 1 to 5 HCl and made up to 100 cc. Potassium was determined gravimetrically by the platonic chloride method. Calcium was determined, by the official method of the Association of Official Agricultural Chemists (1935), involving precipitation with $\text{NH}_4\text{C}_2\text{O}_4$, redissolving with H_2SO_4 , and finally titration with KMnO_4 . For magnesium determination the filtrate from the calcium precipitation was evaporated to 10-cc volume. Next, 7 cc of microcosmic salt solution was added, and then 10 cc concentrated NH_4OH . After standing overnight the precipitate was filtered off and washed with dilute NH_4OH and alcohol. The precipitate and the paper were then added to 20 cc of 0.02 N H_2SO_4 , and digested cold for 3 or 4 hours. The excess acid was titrated with 0.02 N NaOH . Phosphorus was determined colorimetrically by the Fiske and Subbarow method as given by Yoe (1928).

RESULTS WITH THOMPSON SEEDLESS.

In most of the following tables and discussions, the individual experimental lots are grouped into classes according to the Balling degree of the juice of the fresh grapes. Thus all Thompson Seedless lots testing between 17.5° and 18.4° were grouped into the class designated 18 in the left-hand column of each table. Class 19 includes all lots from 18.5° to 19.4° ; class 20 those from 19.5° to 20.4° ; and so on to class 29, which includes all lots from 28.5° to 29.7° . The number of lots in each class is shown in the second and third columns of table 1. Dashes in the tables indicate absence of data. All observations and calculations involving the "dry weight" of the raisins are reported on the basis of 15 per cent moisture in the raisins. To aid in analyzing and interpreting the data, standard errors, derived by the formula $\sqrt{\frac{\sum d^2}{n(n-1)}}$, are given wherever they appear to have value.

The Relation of the Drying Ratio to the Balling Degree of the Fresh Grapes.—The dry weight of the raisins obtained from a unit quantity of fresh Thompson Seedless grapes increased regularly with advancement in maturity of the grapes. The drying ratios, therefore, vary inversely with the Balling degree of the fresh grapes as shown in table 1. All artificially dehydrated lots, pretreated in various ways as described under "Methods of Drying," have been grouped in the columns of table 1 headed "Dehydrated." Likewise all lots dried without the use of artificial heat, whether dried in direct sunlight or in shade, have been grouped in the "Sun-dried" columns.

The drying ratios of the dehydrated lots were consistently more favorable than those of similar sun-dried lots except in the 28° Balling class, where the difference is negligible but in the opposite direction. The differences between dehydrated and sun-dried lots appear to be slightly greater in the low Balling range than in the high range—that is, 25° Balling and above. The coefficient of correlation of drying ratio with Balling degree of the fresh grapes is -0.962 for the dehydrated and -0.951 for the sun-dried lots (table 5).

TABLE 1
RELATION OF THE DRYING RATIO TO THE BALLING DEGREE OF THE FRESH
GRAPES IN THOMPSON SEEDLESS

Degree Balling of fruit	Number of lots		Drying ratio*		Balling $\times$ drying ratio†	
	Dehy- drated	Sun- dried	Dehydrated	Sun-dried	Dehydrated	Sun-dried
18.....	14	12	4.79 $\pm$ 0.034	4.88 $\pm$ 0.052	85.5 $\pm$ 0.344	87.3 $\pm$ 0.835
19.....	4	2	4.35	4.45	83.9	85.2
20.....	11	6	4.35 $\pm$ 0.036	4.50 $\pm$ 0.053	85.7 $\pm$ 0.584	88.3 $\pm$ 1.016
21.....	13	13	4.04 $\pm$ 0.018	4.17 $\pm$ 0.028	84.9 $\pm$ 0.342	87.4 $\pm$ 0.595
22.....	26	31	3.80 $\pm$ 0.010	3.88 $\pm$ 0.016	83.7 $\pm$ 0.176	85.4 $\pm$ 0.310
23.....	23	27	3.63 $\pm$ 0.012	3.71 $\pm$ 0.027	83.9 $\pm$ 0.160	85.8 $\pm$ 0.297
24.....	17	18	3.47 $\pm$ 0.016	3.57 $\pm$ 0.027	83.7 $\pm$ 0.353	83.3 $\pm$ 0.841
25.....	35	35	3.41 $\pm$ 0.003	3.46 $\pm$ 0.012	84.3 $\pm$ 0.216	85.0 $\pm$ 0.255
26.....	5	0	3.18	—†	83.7	—
27.....	16	17	3.12 $\pm$ 0.005	3.13 $\pm$ 0.018	83.9 $\pm$ 0.446	83.9 $\pm$ 0.485
28.....	7	8	3.04 $\pm$ 0.021	3.03 $\pm$ 0.015	84.5 $\pm$ 0.276	85.1 $\pm$ 0.377
29.....	3	5	2.79 $\pm$ 0.006	2.82 $\pm$ 0.015	82.9 $\pm$ 0.562	83.8 $\pm$ 0.449
Mean.....					84.21	85.55

* Raisins, 15 per cent moisture.

† Arithmetical means of calculations on individual lots.

‡ Dashes indicate data not available.

In the last two columns of table 1 appear the products of the Balling degree multiplied by the respective drying ratios. The figures given are the arithmetical means of calculations on the individual lots in each class. The mean of these products for all dehydrated lots is 84.21; for all sun-dried lots, 85.55. The figures exhibit no appreciable correlation with maturity. They fall so closely around the mean as to indicate that the relation of the drying ratio to the Balling degree (maturity) of the fresh grapes approximates that of a straight-line function, the value of the constant differing, of course, with the method of drying employed.

The fluctuations were greater in the data on the sun-dried lots than in those on the dehydrated lots, probably because of the lesser degree of control that could be exercised over drying conditions and over sources of minor losses. Direct losses of entire berries were not, however, entirely responsible for the differences shown between the dehydrated and sun-

dried lots, for the raisin berries were slightly heavier in most dehydrated lots than in equivalent sun-dried lots (table 2).

The Relation of the Weight of Berry and the Weight per Unit Volume of the Raisins to the Balling Degree of the Fresh Grapes.—Table 2 gives the weight per 100 raisin berries and the weight per 500-cc volume measurements on the experimental lots, grouped into Balling-degree classes. The figures show, with some irregularities, a gradual and steady increase in the weight of raisin berries and in weight per unit volume as the total soluble-solids content of the fresh grape berries increases. The

TABLE 2

RELATION OF THE BALLING DEGREE OF FRESH GRAPES TO THE WEIGHT OF BERRY AND THE WEIGHT PER UNIT VOLUME OF THE RAISINS, IN THOMPSON SEEDLESS

Degree Balling of fruit	Weight per 100 raisin berries, grams*		Weight per 500 cc volume of raisins, grams	
	Dehydrated	Sun-dried	Dehydrated	Sun-dried
18.....	26.1±0.522	26.0±0.507	316±4.15	310±5.28
19.....	—†	—	—	—
20.....	31.8±0.325	31.0±0.294	324±8.15	329±8.23
21.....	35.8±0.946	35.4±1.153	345±5.03	341±3.71
22.....	38.6±0.771	37.7±0.756	346±4.85	346±3.37
23.....	40.5±0.747	38.9±0.540	344±4.80	356±4.33
24.....	39.6±0.740	38.3±0.866	353±5.63	354±3.19
25.....	43.6±0.638	42.2±0.682	351±4.11	361±3.08
26.....	—	—	—	—
27.....	47.7±1.220	46.7±1.033	360±5.68	365±5.23
28.....	48.1±1.277	44.3±1.179	351±4.43	377±7.09
29.....	44.3±0.537	45.3±1.005	367±6.75	378±7.15

* Data adjusted to the basis of 15 per cent moisture in the raisins.

† Dashes indicate data not available.

increase in weight of raisin berry from 18° to 29° Balling in the fresh fruit was roughly 70 per cent; the increase in weight per unit volume over the same range of maturity, about 18 per cent. The figures of table 2 show small differences in raisin-berry weights between the dehydrated and sun-dried lots in favor of the dehydrated lots by odds of about 150 to 1 when the data are analyzed by Student's (1908, 1917) method. Most of the sun-dried lots appear to have had a higher weight per unit volume than did similar dehydrated lots. Since, however, the figures for dehydrated lots in table 2 lack consistency in respect to this measurement, the odds by Student's method are only 26 to 1 in favor of the sun-dried.

The rather positive, although small, differences in berry weights in favor of the dehydrated lots indicate that respiration, and perhaps fermentation in some lots, used up some of the grape solids in the sun-dried fruit. The data on the sugar content of the raisins (table 3) tend to

substantiate this hypothesis, showing a higher percentage of sugar in the dehydrated than in the sun-dried lots.

The coefficient of correlation of raisin-berry weight with Balling degree of the fresh fruit was 0.860 for the dehydrated lots, and 0.699 for the sun-dried. The coefficient of correlation of the weight per unit volume measurements on the raisins with the Balling degree of the fresh fruit was 0.454 for the dehydrated, 0.625 for the sun-dried lots (table 5).

The Relation of the Composition of the Raisins to the Balling Degree of the Fresh Grapes.—The sugar content of the raisins increased with

TABLE 3
RELATION OF BALLING DEGREE OF THE FRESH GRAPES TO THE SUGARS AND
INSOLUBLE SOLIDS OF THE RAISINS, IN THOMPSON SEEDLESS*

Degree Balling of fruit	Per cent sugars†		Per cent insoluble solids‡	
	Dehydrated	Sun-dried	Dehydrated	Sun-dried
18.....	69.5±0.246	68.7±0.313	6.38±0.166	7.06±0.233
19.....	—§	—	—	—
20.....	70.4±0.829	69.6±0.584	7.05±0.403	6.66±0.178
21.....	70.9±0.295	71.0±0.246	6.23±0.254	6.12±0.132
22.....	72.0±0.218	71.2±0.360	5.60±0.141	5.91±0.064
23.....	72.3±0.173	71.4±0.282	5.70±0.135	5.65±0.062
24.....	72.8±0.347	71.5±0.520	5.83±0.259	5.69±0.074
25.....	72.7±0.169	71.9±0.363	5.26±0.107	5.29±0.070
26.....	—	—	—	—
27.....	72.9±0.233	71.5±0.273	4.87±0.086	5.29±0.083
28.....	72.2±0.541	71.0±0.313	5.15±0.322	5.08±0.129
29.....	73.0±0.276	71.7±0.458	4.52±0.076	4.98±0.172

* Data adjusted to the basis of 15 per cent moisture in the raisins.

† Reducing sugars calculated as invert sugars.

‡ Insoluble residue from water extraction in the Soxhlet apparatus.

§ Dashes indicate data not available.

the maturity of the grapes during the early part of the maturation period—from 18° to 23° or 24° Balling (table 3). After the grapes had reached 24° Balling, the sugar content of the raisins apparently increased but little, if at all. At 18° Balling the sugar content of the raisins was 69.5 per cent and 68.7 per cent, respectively, for dehydrated and sun-dried lots; whereas at 24° Balling it was 72.8 per cent and 71.5 per cent, respectively, calculated as invert sugars and based on raisins of 15 per cent moisture content.

The dehydrated lots had higher sugar content than the sun-dried by 1.3 per cent of the sun-dried.

The coefficient of correlation of sugar content of the raisins with the Balling degree of the fresh grapes over the entire range of maturity studied was 0.474 in the dehydrated, 0.394 in the sun-dried lots (table 5).

The water-insoluble solids of the raisins varied inversely with the sugars, decreasing, as maturity advanced, from about 7.0 per cent in

the raisins made from grapes of 18° or 19° Balling to about 5.7 per cent at 23° or 24° Balling and to about 5.0 per cent in the raisins made from the ripest grapes. The differences in insoluble-solids content shown in table 3 between the dehydrated and sun-dried lots are not significant.

The coefficient of correlation of insoluble solids in the raisins with the Balling degree of the fresh fruit was -0.460 in the dehydrated lots, -0.693 in the sun-dried (table 5).

The total titratable acidity of the raisins decreased markedly with increased maturity of the fresh grapes in the early part of the ripening

TABLE 4

RELATION OF BALLING DEGREE AND TITRATABLE ACID IN THE FRESH GRAPES TO THE TITRATABLE ACID IN THE RAISINS, IN THOMPSON SEEDLESS

Degree Balling of fruit	Per cent acid in fresh fruit*	Percentage of acid in fresh fruit $\times$ drying ratio†		Per cent acid in raisins*‡	
		Dehydrated	Sun-dried	Dehydrated	Sun-dried
18.....	0.79	3.82±0.027	3.92±0.041	3.47±0.111	3.37±0.123
19.....	—§	—	—	—	—
20.....	0.69	3.06±0.025	3.13±0.037	2.81±0.133	2.88±0.261
21.....	0.66	2.69±0.012	2.76±0.018	2.45±0.077	2.47±0.084
22.....	0.59	2.16±0.006	2.26±0.009	2.16±0.070	2.11±0.052
23.....	0.54	1.85±0.007	1.94±0.015	1.91±0.083	1.93±0.050
24.....	0.51	1.71±0.008	1.88±0.014	1.83±0.098	1.92±0.095
25.....	0.46	1.52±0.002	1.61±0.006	1.70±0.043	1.70±0.040
26.....	—	—	—	—	—
27.....	0.42	1.26±0.002	1.37±0.008	1.59±0.061	1.55±0.050
28.....	0.42	1.24±0.009	1.30±0.006	1.68±0.098	1.49±0.092
29.....	0.44	1.24±0.003	1.26±0.007	1.62±0.163	1.47±0.056

* Per cent acid by weight calculated as tartaric acid.

† Means of computations on individual lots.

‡ Water extract titrated with 0.033 normal NaOH to phenolphthalein indicator and calculated as tartaric acid.

§ Dashes indicate data not available.

period (table 4). As the grapes became more mature, the decrease in acidity of the raisins became less. Titration figures on the fresh grape juice (table 4, second column) show a similar trend. The total acid content of the fresh grapes appears to decrease rapidly early in the ripening period, but more slowly or not at all later on.

To judge from the rather rapid decrease in the total titratable acid content of the raisins in the early part of the ripening period of the grapes, a method of grading raisins for quality on the basis of acid determination on the raisin pulp may have considerable practical value.⁷ It apparently provides an index of the approximate maturity of the grapes within the range of its application, which is indicated in this investigation to be between 18° and 23° Balling.

⁷ Such a method has been proposed by Mr. Charles D. Fisher of the Dried Fruit Association of California (unpublished).

The coefficient of correlation of the total titratable acidity of the raisins with the Balling degree of the fresh grapes was -0.741 for the dehydrated, -0.777 for the sun-dried lots (table 5).

Table 4 shows no consistent differences in acid content between the dehydrated and sun-dried raisins. (The odds are only 8.9 to 1, by Student's method, that the dehydrated lots as a group are higher.)

Table 4 gives also the titratable acidity of the fresh grapes multiplied by the drying ratio (from table 1) in order that these calculated quantities may be compared with the total titratable acid content as determined on the raisins. As the figures show, in the early part of the ripening period—until the fresh grapes reach 22° or 23° Balling—the

TABLE 5
COEFFICIENTS OF CORRELATION BETWEEN BALLING DEGREE OF THE
FRESH GRAPES AND VARIOUS DETERMINATIONS ON THE
RAISINS, IN THOMPSON SEEDLESS

Determinations	Dehydrated lots	Sun-dried lots
Drying ratio.....	-0.962	-0.951
Sugars.....	0.474	0.394
Titratable acids.....	-0.741	-0.777
Insoluble solids.....	-0.460	-0.693
Weight per 100 raisin berries.....	0.860	0.699
Weight per unit volume.....	0.454	0.625

titratable acid in the raisins is less than the calculated amount, assuming that there was no change in the nature of the acids of the fresh grapes as a result of drying. In the later part of the ripening range—above 22° or 23° Balling—the total acid content of the raisins is consistently greater than the calculated amount. The data are very consistent in both the dehydrated and sun-dried lots, and the reversal of trend in the figures is probably not due to any errors in the empirical procedures followed in titrating either the fresh grape juice or the water extracts of the raisins. The phenomenon may be explained, conceivably, by changes in the composition of the grapes, perhaps precipitation of potassium bitartrate in the grape tissues, part of the precipitate being lost in the discarded fresh grape pulp but redissolved in the prolonged water extraction of the raisin pulp. It has not, however, been possible to make the necessary investigations to verify or disprove this hypothesis.

The content (percentage) of potassium, calcium, and magnesium of the Thompson Seedless raisins appears to remain nearly constant over the entire range of maturity of the grapes used in the investigations (table 6). The data of table 6 appear to indicate that phosphorus may

decrease slightly in the raisins as the maturity of the grapes advances; but the consistency in the figures is not sufficient to establish the apparent decrease as a fact.

The potassium content of the raisins averaged 0.905 per cent, the calcium 0.058 per cent, the magnesium 0.027 per cent, and the phosphorus 0.105 per cent.

TABLE 6

RELATION OF BALLING DEGREE OF THE FRESH GRAPES TO THE POTASSIUM, CALCIUM, MAGNESIUM, AND PHOSPHORUS CONTENT OF THE RAISINS, IN THOMPSON SEEDLESS*

Degree Balling of fruit	Potassium (per cent K)		Calcium (per cent Ca)		Magnesium (per cent Mg)		Phosphorus (per cent P)	
	Dehy- drated	Sun- dried	Dehy- drated	Sun- dried	Dehy- drated	Sun- dried	Dehy- drated	Sun- dried
18.....	0.862	0.891	0.061	—†	0.026	—	0.115	0.114
19.....	—	—	—	—	—	—	—	—
20.....	0.946	0.935	0.057	0.072	0.029	0.029	0.107	0.108
21.....	0.865	0.864	0.056	—	0.022	—	0.105	0.104
22.....	0.914	0.938	0.052	0.050	0.021	0.029	0.110	0.111
23.....	0.852	0.909	0.059	—	0.020	—	0.107	0.104
24.....	0.935	0.973	0.057	0.051	0.032	0.033	0.107	0.106
25.....	0.871	0.909	0.063	0.066	0.018	0.021	0.106	0.103
26.....	—	—	—	—	—	—	—	—
27.....	0.880	0.898	0.060	0.051	0.030	0.035	0.104	0.106
28.....	0.935	0.966	0.057	—	0.033	—	0.100	0.095
29.....	0.891	0.874	0.050	—	0.020	—	0.097	0.097

* Data adjusted to the basis of 15 per cent moisture in the raisins.

† Dashes indicate data not available.

The Relation of the Balling Degree of the Grapes to Quality in the Raisins.—The weight of the raisin berries and the weight per unit volume* are accepted factors in the measurement of quality in raisins.

The data on weight of berry, weight per unit volume, sugar content, acidity, and insoluble-solids content indicate a continued improvement in the quality of the raisins as the grapes mature, the improvement proceeding rapidly during the early part of the ripening period, slowing in its middle part, and almost ceasing as the grapes become very ripe.

Representative samples from the experimental lots of "naturals" and golden-bleached raisins were submitted to a group representing the principal commercial raisin packers of the state. Tabulation of their grading of the samples showed continuous improvement in quality over the entire ripening range.

* The weight per unit volume measurement, based on the work of Chace and Church (1927), has been used by a large cooperative organization for many years to grade growers' lots of raisins when received at the warehouse. Differential payments have been made upon the basis of this measurement.

The Influence of the Method of Drying on the Drying Ratio, Sugar Content, and Acid Content of Thompson Seedless Raisins.—In tables 1 to 4, inclusive, all dehydrated lots and all sun- or shade-dried lots were grouped together to show the relations existing between the maturity of the fresh grapes and the several factors measured in the raisins. The predrying treatments—dipping and sulfuring—as well as the manner of drying did, however, materially influence the yield and composition of the raisins.

TABLE 7

THE INFLUENCE OF METHOD OF DRYING ON DRYING RATIO, SUGAR CONTENT OF THE RAISINS, AND TOTAL TITRATABLE ACIDITY OF THE RAISINS, IN THOMPSON SEEDLESS

Method of drying	Balling degree $\times$ drying ratio*	Percentage sugar (as invert) in raisins from grapes of 23° Balling	Percentage acid (as tartaric) in raisins from grapes of 23° Balling
(1) Natural sun-drying.....	87.8	70.4	1.88
(2) Dehydration without pretreatment.....	84.5	72.2	2.01
(3) Lye dip with dehydration.....	84.1	72.2	1.86
(4) Lye dip with sun-drying.....	85.5	71.9	1.77
(5) Golden bleach.....	83.6	72.5	2.41
(6) Sulfur bleach.....	85.0	72.3	2.34
(7) Australian mixed dip with dehydration.....	84.3	72.2	1.83
(8) Australian mixed dip with rack-drying.....	85.0	71.7	1.80
(9) Australian cold dip with dehydration.....	84.1	72.3	1.61
(10) Australian cold dip with rack-drying.....	85.0	70.7	1.77
(11) California soda-oil dip with dehydration.....	84.5	72.3	1.56
(12) California soda-oil dip with sun-drying.....	86.4	71.3	1.86

* Means of the products calculated individually for each lot by multiplying the Balling degree by the drying ratio. Dividing the quantities given in this column by any Balling degree, from 18° to 29°, gives the approximate drying ratio obtained with Thompson Seedless grapes at that degree Balling for the respective method of drying.

Table 7 shows how the several treatments used and the manner of drying affected the product of the Balling degree multiplied by the drying ratio, the sugar content of the raisins, and their total titratable acidity. The Balling degree $\times$ drying ratio figures are averages of the quantities obtained by calculating this product separately for each lot dried by the respective methods. It is a convenient expression since the drying ratio obtained with Thompson Seedless grapes at any given Balling degree between 18° and 29° can be very closely approximated by simply dividing it by the Balling degree. The percentages of sugar and acid are given in table 7 only for raisins made from grapes of 23° Balling. The differences obtained in sugar and acid among the various methods of drying, increased slightly with grapes of lower degree Balling but remained fairly constant above 23° Balling. Means calculated from the figures given in table 7 for methods of drying involving arti-

ficial dehydration and for methods involving sun- or shade-drying will be found to differ slightly from the figures given in tables 1, 3, and 4. The apparent inconsistencies do not indicate discrepancies in the data nor in their interpretation but are the result of not having the same number of lots represented in each method of drying. Methods 4, 7, 9, 11, and 12 were used only during the 1935 season, hence fewer lots dried by these methods than by the other methods are represented in tables 1, 3, and 4.

The dehydrated lots all yielded better drying ratios, as indicated by lower values for Balling degree $\times$ drying ratio, than equivalent sun- or rack-dried lots. All methods involving a predrying treatment gave better ratios than natural sun-drying. The most favorable ratios were obtained with the golden bleach (method 5), but the advantage of this method over others involving dehydration is small. Hot lye dipping improved the drying ratio in the sun-dried lots, and the sulfured lots (methods 5 and 6) came out slightly more favorably than those lye dipped but not sulfured (methods 3 and 4). The potassium carbonate and oil dips (methods 7 to 10) were roughly equal to the hot lye dip in their effect on drying ratio. Differences of less than 0.5 in the Balling degree $\times$ drying ratio are not significant.

The golden-bleached raisins (method 5) had the highest apparent sugar content. In the percentage-sugar column of table 7, differences of less than 0.5 are not significant. No differences may be assumed to exist, therefore, among equivalent lots dried according to methods 2, 3, 4, 6, 7, 9, and 11; all of these are, however, definitely higher than the natural sun-dried, but the differences between any of these methods and method 5 are of doubtful significance. The raisins made by methods 8 and 12 (table 7) are intermediate in sugar content, higher than the natural sun-dried, and lower than the golden bleached. Method 10 produced raisins of about the same sugar content as the "naturals" (method 1).

The sulfured lots (methods 5 and 6) are clearly higher in titratable acid than any others. No determinations for SO_2 were made; but, assuming the raisins to be analogous to similar commercial samples, a reasonable estimate of the SO_2 in them would approximate 1,000 parts per million (0.1 per cent). If the SO_2 present was all titratable, which it probably is not, and was expressed in terms of tartaric acid, it would account for about 0.23 per cent acid or slightly less than half of the difference found between the golden-bleached raisins (method 5) and those of method 3, which had no sulfur dioxide but which were otherwise treated similarly. The remainder of the apparent differences shown between methods 5 and 3 and methods 6 and 4 are unaccounted for. Differences of 0.12 or greater in the total-acid column of table 7 are required for significance (20 to 1 odds). The strong carbonate dips of

methods 9 and 11 reduced the apparent acid content of the raisins, probably as a result of surface adherence of some of the dipping solution. These raisins were not washed after drying. The raisins of methods 10

TABLE 8

THE RELATION BETWEEN THE SIZE OF CROP, MATURITY, AND SIZE OF BERRY IN
THOMPSON SEEDLESS GRAPES, AT DAVIS

Picking date	Degree Balling	Weight per 100 berries, grams	Degree Balling	Weight per 100 berries, grams
1927	Vines of moderate crop (6 tons per acre)		Vines of heavy crop (9 tons per acre)	
September 6.....	22.5	128	20.3	119
September 10.....	23.0	131	21.4	120
September 17.....	23.0	130	22.3	118
September 24.....	24.3	135	22.2	121
October 1.....	25.0	133	23.4	120
October 8.....	26.1	139	23.7	122
October 15.....	27.0	137	24.5	122
October 22.....	26.5	140	—*	120
1935	Vines of moderate crop (7 tons per acre)		Vines of heavy crop (12 tons per acre)	
August 31.....	21.0	129	18.2	127
September 7.....	19.6	130	17.4	120
September 13.....	22.1	136	21.0	136
September 20.....	23.8	142	21.9	161
September 27.....	23.4	138	22.4	152
October 4.....	24.6	144	23.0	169
October 11.....	24.4	143	24.8	157
October 18.....	24.3	144	24.6	167
1936	Vines of light crop† (3 tons per acre)		Vines of moderate crop (6 tons per acre)	
August 22.....	21.9	130	21.6	134
August 29.....	24.4	140	22.9	137
September 4.....	24.5	144	23.3	137
September 11†.....	26.8	136	24.8	136
September 18.....	28.0	136	25.1	134
September 25.....	29.7	137	26.5	138
October 2.....	—	—	27.0	139

* Dashes indicate data not available.

† The first three pickings exhausted the supply of fruit on the vines used August 22 to September 4, inclusive. Another group of vines was used to supply the fruit for the September 11 to September 25 tests from the light-crop vines.

and 12, which received predrying treatments identical with those of methods 9 and 11 respectively, were washed after drying. They show no considerable decrease in acidity resulting from the treatment. The differences in acid content between dehydrated and equivalent sun-dried lots is small except in the lots dried by method 9 as compared with 10 and

those of method 11 as compared with 12. The probable reason for these differences has already been explained.

The Relation Between Size of Crop, Maturity, and Size of Berry.—Table 8 shows the picking dates and Balling degree of the fresh grapes, and the weight per 100 berries for each series of experimental lots obtained from the vineyards at Davis. The crop weights given in the table were arrived at by adding together all quantities removed from the vines, plus the estimated amount of fruit remaining unharvested at the end of the season, and then calculating to the acre basis.

The data are inconclusive. The figures show that in 1927 the vines carrying the heavy crop were a little slower in ripening their fruit and produced somewhat smaller berries than did the vines having only a moderate crop. Also, the berries from the moderately loaded vines apparently increased in size, at least during the early part of the ripening period, whereas those from the heavily loaded vines did not.

In 1935, the fruit from the heavily loaded vines was a little greener early in the season, but caught up with that from the moderately loaded vines before the season was over. The berries from both lots of vines increased in size during the early part of the ripening season, and after the third picking those from the heavily loaded vines were larger than those from the moderately loaded vines.

In 1936, two different sets of lightly loaded vines were required to supply the needed quantity of fruit. The two groups of vines were very similar, but not identical in their characteristics, as is indicated by the break in berry-size increase when the change to the second set of vines was made on September 11. The fruit on the lightly loaded vines ripened slightly ahead of that from the moderately loaded vines. Some increase in berry size is indicated as ripening progressed in the fruit from the first set of lightly loaded vines, but none is indicated in the second set of lightly loaded vines nor in the moderately loaded vines.

RESULTS WITH MUSCAT OF ALEXANDRIA

The work with the Muscat paralleled that with Thompson Seedless during the 1935 and 1936 seasons, but involved a total of only 76 individual lots as against a total of 348 (in four years) for Thompson Seedless. The data obtained are therefore less extensive and not so consistent when summarized. The methods of drying used were those described for Thompson Seedless as (1) natural sun-drying; (2) dehydration without pretreatment; (3) lye dip with dehydration; (4) lye dip with sun-drying; (9) Australian cold dip with dehydration; and (10) Australian cold dip with rack-drying. The complete series was carried through 1935; but in 1936 it was impossible to follow the entire program, and

TABLE 9

RELATION OF BALLING DEGREE TO CERTAIN DETERMINATIONS ON THE FRESH GRAPES AND RAISINS, IN MUSCAT OF ALEXANDRIA *

Degree Balling of fruit	Fresh fruit		Raisins									
	Per cent acid, as tartaric	Weight per 100 berries, grams		Drying ratio		Drying ratio × Balling degrees		Weight per 100 raisin berries, grams		Weight per 500 cc raisins, grams		
		1935	1936	Number of lots		Dehy- drated	Sun- dried	Dehy- drated	Sun- dried	Dehy- drated	Sun- dried	
				Dehy- drated	Sun- dried							
16.0.....	0.69	423	—†	3	2	4.95	4.92	79.0	78.7	84	284	297
17.1.....	0.66	407	—	3	2	4.68	4.70	79.9	80.4	90	310	305
18.6 and 18.7.....	0.59	400	392	5	4	4.25	4.45	79.9	83.0	91	323	297
19.1 and 19.2.....	0.45	435	—	6	3	4.16	4.30	78.9	82.5	109	107	298
19.7 and 20.6.....	0.48	491	390	5	3	3.89	4.08	78.7	81.6	112	104	306
21.3 and 21.4.....	0.44	480	405	5	3	3.78	3.86	80.7	82.4	120	111	309
22.4 and 22.7.....	0.36	454	—	5	1	3.61	3.83	81.6	86.9	132	120	317
23.1 and 23.3.....	0.38	—	403	4	2	3.51	3.60	81.3	83.8	116	113	321
24.7 and 25.4.....	0.39	—	405	8	2	3.27	3.37	82.0	84.5	123	119	330
27.0 and 27.5.....	0.37	—	393	6	4	3.00	3.06	81.9	84.1	130	129	331

* Data adjusted to the basis of 15 per cent moisture in the raisins.

† Dashes indicate data not available.

methods 9 and 10 were dropped. A considerable number of the sun-dried lots were discarded in which 10 per cent or more of the berries showed a positive reaction to the yeast and mold test with hydrogen peroxide.

Tables 9 and 10 summarize the results. The individual lots are grouped according to the Balling degree of the fresh fruit; but, since each class represents only one or two series, the actual Balling hydrometer readings are given in the left-hand column of each table. The acid titrations, calculated to per cent by weight as tartaric, are averaged in the second column of table 9. A marked decrease in the acidity of the fresh fruit is apparent until the fruit reached about 22° Balling, after which no further decrease was observed. Also, the acid content of the grapes in 1936 was slightly higher than in 1935, a fact which accounts for the minor discrepancies in the continuity of the decrease in acid as shown in table 9.

The size of the fresh berries (table 9, third and fourth columns) was appreciably greater in 1935 than in 1936. An increase in size during the early part of the ripening period is, furthermore, indicated.

The drying ratios for both dehydrated and sun-dried lots decreased without a break in continuity from the greenest to the ripest lots. When the drying ratio of the Muscat is multiplied by the Balling degree, the product shows a definite trend to increase as the fruit becomes riper, in contrast to the results with Thompson Seedless (table 1), with which the product of Balling $\times$ drying ratio shows no tendency to drift with the Balling. The difference in behavior of the two varieties in this respect is logically attributed to the presence of seeds in the Muscat and their absence in the Thompson Seedless. If the seeds in the Muscat are assumed to be nearly mature in the greenest fruit used and to change but little as the sugar content of the grapes increases, then the effect on the relation of the drying ratio to the Balling degree would be as observed in these tests.

The weight per 100 raisin berries is influenced both by the size of the fresh berries and by the drying ratio. Since the fresh berries were larger in 1935 than in 1936, and since the lots in the lower Balling classes are preponderantly from the 1935 experiments, whereas the higher Balling classes were mostly obtained in 1936, the size of raisin berries as the fruit becomes more mature progresses upward less regularly than if the tests could have covered the entire range of maturity in both years. Nevertheless, the figures of table 9 show a 50 per cent increase in size of the raisin berries from the greenest to the ripest fruit used. Since commercial grading with Muscat raisins is largely based on size, obviously the commercial quality improved gradually over the entire range of maturity studied.

TABLE 10
THE RELATION BETWEEN BAILING DEGREE OF THE FRESH GRAPES AND COMPOSITION OF THE RAISINS, IN MUSCAT OF ALEXANDRIA*

Degree Bailing of fruit	Sugars (per cent, as invert)		Acid (per cent, as tartaric)		Insoluble solids, (per cent)		Potassium (per cent K)		Phosphorus (per cent P)		Calcium (per cent Ca)		Magnesium (per cent Mg)	
	Dehy- drated	Sun- dried	Dehy- drated	Sun- dried	Dehy- drated	Sun- dried	Dehy- drated	Sun- dried	Dehy- drated	Sun- dried	Dehy- drated	Sun- dried	Dehy- drated	Sun- dried
16.0	62.8	62.2	3.16	2.67	13.5	15.3	0.796	0.794	0.101	0.100	—†	—	—	—
17.1	64.7	63.8	2.83	2.21	11.8	13.6	0.773	0.784	0.098	0.099	0.074	0.076	0.030	0.033
18.5 and 18.7	64.8	64.2	2.60	2.02	12.8	13.1	—	—	—	—	—	—	—	—
19.1 and 19.2	66.5	65.9	2.18	1.82	11.5	12.0	0.700	0.771	0.094	0.095	0.062	0.073	0.024	0.026
19.7 and 20.6	67.2	65.5	1.83	1.69	11.3	11.7	0.701	0.774	0.089	0.097	—	—	—	—
21.3 and 21.4	65.0	66.9	1.65	1.50	10.5	11.7	0.652	0.670	0.090	0.095	0.059	0.070	0.019	0.026
22.4 and 22.7	69.4	68.0	1.60	1.44	9.5	11.2	—	—	—	—	—	—	—	—
23.1 and 23.3	68.2	67.4	1.53	1.34	10.9	10.5	0.665	0.706	0.082	0.087	0.072	0.072	0.017	0.020
24.7 and 25.4	68.8	67.2	1.43	1.28	10.1	10.1	0.665	0.713	0.086	0.097	0.067	0.061	—	0.019
27.0 and 27.5	68.7	68.0	1.24	1.18	10.0	10.6	0.665	0.694	0.086	0.085	0.077	0.073	0.024	0.024

* Data adjusted to the basis of 15 per cent moisture in the raisins.

† Dashes indicate data not available.

The weight per unit volume of the Muscat raisins (table 9) shows a clear increase in this measurement as the grapes became ripier, but an increase neither so regular nor so great as in Thompson Seedless (table 2).

In the early part of the ripening range the Muscat raisins showed a marked increase in sugar as the grapes became ripier. Grapes of 16.0° Balling produced raisins having 62.8 per cent and 62.2 per cent sugar respectively for the dehydrated and sun-dried lots, whereas raisins made from grapes of 23.1°–23.3° Balling had 68.2 and 67.4 per cent sugar (table 10). Beyond the 23° Balling stage of maturity the sugar content of the raisins did not increase further with more advanced maturity of the grapes.

The total titratable acid content of the raisins decreased with advancing maturity, rapidly at first, then more slowly, but continued over the entire range of maturity. Raisins made from grapes at 16.0° Balling had 3.16 and 2.67 per cent total acid as tartaric in the dehydrated and sun-dried lots respectively, those from grapes of 23.1°–23.3° Balling had 1.53 and 1.34 per cent acid, and those from grapes of 27.0°–27.5° Balling had 1.24 and 1.18 per cent. The acid content of the sun-dried lots was consistently lower than that of equivalent dehydrated lots.

The water-insoluble solids content of the Muscat raisins, which included much of the seed materials, decreased from 13.8 and 15.3 respectively in dehydrated and sun-dried lots made from grapes of 16.0° Balling to between 10 and 11 per cent from grapes of 23.1°–23.3° Balling; thereafter it decreased but little, if at all.

Potassium and phosphorus in the raisins (table 10) decreased slightly in percentage as the maturity of the fresh grapes advanced. The decrease is small but too consistent to be ignored. Calcium and magnesium in the raisins seem to remain about the same over the entire range of maturity of the fresh grapes.

When compared with Thompson Seedless (table 6) the Muscat raisins were slightly lower in potassium and phosphorus content, slightly higher in calcium, and about the same in magnesium.

SUMMARY

Experiments were conducted to determine how the maturity of the fresh grapes influences the drying ratio, the size of the raisin berries, the weight per unit volume, the titratable acidity, and the content of sugar, potassium, calcium, magnesium, and phosphorus in the raisins. Thompson Seedless (Sultanina) and Muscat of Alexandria grapes, picked at about weekly intervals, were dried by several methods, including most of the standard commercial procedures and certain others that are not

commercial. The stage of maturity is represented by degree Balling of the juice from the fresh grapes. The tests with Thompson Seedless covered a range of 18° to 29° Balling and with Muscat 16° to 27°.

As the maturity of the fresh Thompson Seedless grapes advanced, the drying ratio decreased regularly with the increase in Balling degree, so that the product of Balling degree $\times$ drying ratio remained nearly constant. With the Muscat of Alexandria, the drying ratio decreased with advancing maturity of the grapes, but not proportionally, and the product of Balling degree $\times$ drying ratio drifted upward with the Balling. The size of the raisin berries and the weight per unit volume of raisins in both varieties increased along with the maturity of the grapes.

During the early part of the range of maturity studied, the sugar content of the raisins increased, whereas the total titratable acidity and insoluble-solids content decreased. The rate of these changes lessened as maturity advanced. Changes in the sugar and insoluble-solids content of the raisins nearly or quite ceased after the midpoint in the range of maturity of the grapes was reached, although the acidity of the raisins continued to decrease slowly.

The potassium, calcium, and magnesium content of the Thompson Seedless raisins remained fairly constant, whereas the phosphorus content appears to have decreased somewhat with advancing maturity. In the Muscat raisins both the potassium and phosphorus decreased, with the calcium and magnesium content remaining about the same.

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**THE EFFECT OF PRETREATMENT AND
SUBSEQUENT DRYING ON THE
ACTIVITY OF GRAPE OXIDASE**

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THE EFFECT OF PRETREATMENT AND SUBSEQUENT DRYING ON THE ACTIVITY OF GRAPE OXIDASE¹

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THOMPSON SEEDLESS GRAPES usually darken during drying in the preparation of raisins. The intensity of this darkening depends to a considerable extent on the treatment of the fresh fruit prior to drying. Raisins prepared by drying grapes in the sunlight without other treatment are characteristically of a dark color similar to the clove-brown of Ridgway (1912).⁵ Raisins produced by the cold-dip, mixed-dip, soda-dip (hot lye), sulfur-bleach, or golden-bleach procedures, on the other hand, usually have a light color ranging in hue from cinnamon-buff to sepia as judged by the color standards of Ridgway. Hussein and Cruess (1940) investigated the properties of grape oxidase and suggested that oxidizing enzymes are involved to a considerable extent in the darkening of grapes during the preparation of raisins, and to some extent in the darkening of wines. These authors, however, limited their investigations to the enzyme preparation obtained from fresh, untreated grapes. There is no available published information concerning the effects of the various treatments used in the production of light-colored raisins on the oxidizing enzymes occurring in grapes.

A series of experiments was conducted during the 1939 season in order to determine the effects of the mixed-, soda-, and cold-dip pretreatments, and of sulfuring and drying, on the oxidase activity of raisins made from Thompson Seedless grapes.

EXPERIMENTAL PROCEDURE

Materials Used.—Thompson Seedless grapes were used in all experiments unless otherwise indicated.

The sulfur-bleach and cold-, mixed-, and soda-dip procedures employed were similar to those in commercial use as described by Mrak and Long (1941). The golden-bleach procedure was similar to that used in the preparation of sulfur-bleach raisins, except that the fruit was dried in a dehydrator having a relative humidity of 25 per cent at the hot end, and a dry-bulb temperature of 71.1° C (160° F).

The dipping preparations used were: soda dip, 0.5 per cent solution of

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NaOH brought to 95° C (203° F) ; mixed dip, an emulsion containing 68 grams of K_2CO_3 , 34 grams of NaOH, 50 cc of California olive oil, and approximately 12 liters of tap water brought to 82.2° C (180° F) ; and cold dip, an emulsion containing 950 grams of an alkali mixture consisting of 95 grams of Na_2CO_3 , 855 grams of K_2CO_3 , 100 cc of California olive oil, and approximately 20 liters water at 20° C (68° F).

Freshly picked Thompson Seedless grapes were treated in one or another of the dipping preparations for various periods of time, then sulfured or dried according to the particular procedure used in commercial practice.

Enzyme Preparation.—Untreated, freshly dipped, sulfured, and dried grapes were tested for oxidase activity after first making an enzyme preparation from the various samples. The enzyme preparations and measurement were made according to the procedures of Hussein and Cruess (1940) as described briefly in the paragraph below. Treated grapes were stored at -17.7° C (0°F), and the raisins at 0° C (32° F) until used.

To make the enzyme preparation, samples were ground in a mortar containing white sand and acetone and were then filtered. This procedure was repeated a second and third time. The dilute acetone prevented browning, removed auto-oxidizable catechol compounds, tannins, some of the water-soluble materials, and precipitated the enzyme. The solid residue was then extracted with a 0.2 molar citrate buffer of pH 4.5, equal in volume in cubic centimeters to three times the weight in grams of the grape sample used. Then three volumes of 95 per cent alcohol were added and the mixture centrifuged. The resulting precipitate was suspended in the aforementioned citrate buffer.

Quantitative Measurement of Grape-Oxidase Action.—The colorimetric method of Bansi and Ucho (1926) as modified by Hussein and Cruess (1940), was used for the quantitative measurement of oxidase activity. This procedure is as follows: 1 cc of enzyme extract and 1 cc of 1 per cent guaiacol solution (by volume) in 50 per cent ethyl alcohol were added to a test tube containing 5 cc of 0.2 molar acetate buffer of pH 4.5. Then sufficient distilled water was added to make a total volume of 20 cc. Finally 1 cc of 0.1 N H_2O_2 was added to the same test tube after which the tube was held at 30° C (86° F) for 1 hour. The reaction was then stopped by the addition of 5 cc of glacial acetic acid. The peroxidase enzyme of the grapes catalyzes the oxidation of the guaiacol by the H_2O_2 , a reaction similar to that occurring during the browning of the grape flesh by oxidation catalyzed by the enzyme.

Hussein and Cruess (1940) estimated enzyme activity by observing the extent to which the extracts darkened. This was conveniently done

by measuring the light transmission with an Evelyn photoelectric colorimeter, with a filter having maximum transmission at 5,400 angstrom units. From the transmissions (T) were calculated values of $\log 1/T$, used as the measure of enzyme activity. The greater the value of $\log 1/T$ the greater is the enzyme activity.

EXPERIMENTAL OBSERVATIONS

Effect of Various Dips.—The effects of the type and time of dip used on enzyme activity of fresh grapes are shown in table 1. The enzyme

TABLE 1
EFFECT OF VARIOUS DIPPING TREATMENTS ON ENZYME ACTIVITY
OF THOMPSON SEEDLESS GRAPES

Type of dip	Dipping period	Per cent of light transmission	Log 1/T values for enzyme activity	Per cent increase or decrease in oxidase activity
Cold dip*.	2 minutes.....	46.25	-0.335	-2.6
	5 minutes†.....	59.00	-0.229	-34.8
	10 minutes.....	64.50	-0.190	-45.0
No dip (check).....		45.00	-0.347	....
Mixed dip‡.	5 seconds†.....	40.00	-0.398	+15.8
	30 seconds.....	56.25	-0.248	-28.0
	60 seconds.....	75.75	-0.120	-64.5
No dip (check).....		45.50	-0.342	....
Soda dip (5 per cent solution of NaOH).....	5 seconds†.....	38.50	-0.415	+14.2
	30 seconds.....	95.25	-0.022	-94.0
	60 seconds.....	98.75	-0.004	-99.0
No dip (check).....		43.50	-0.362	....

* An emulsion containing 950 grams of alkali mixture (95 grams of Na_2CO_3 and 855 grams of K_2CO_3) and 100 cubic centimeters of olive oil and about 20 liters of tap water.

† Dipping periods commonly used in commercial practice.

‡ An emulsion containing 68 grams of K_2CO_3 , 34 grams of NaOH, 50 cubic centimeters of olive oil, and 12 liters of tap water.

activity of grapes treated in the cold dip decreased when the length of dipping period was increased. This decrease in enzyme activity, however, was not directly proportional to the length of dipping period used. The skin of grapes treated in the cold dip did not crack, even after 10 minutes' exposure, but much of the waxy bloom was removed. The amount removed varied according to the length of the dipping period. Each skin was covered with a thin layer of oil which caused the fruit to remain soft and pliable, even when dried. This oil coating may have acted as a layer retarding the entrance of oxygen into the flesh of the fruit, thereby preventing in some degree, darkening of the raisins by oxidation.

Immersion of grapes for an appreciable period of time in the hot dipping solutions reduced the enzyme activity, whereas dipping for a very short time increased enzyme activity. When the dipping period was increased to 30 seconds or more, enzyme activity decreased rapidly as shown in table 1. The most rapid decrease in enzyme activity occurred when the grapes were treated in the soda dip, while the slowest decrease in activity occurred when they were treated in the cold dip. The temperature of the dipping solution was undoubtedly an important factor in accounting for these differences. In order to determine the effect of heat alone on the enzyme activity, dipping tests were conducted in distilled

TABLE 2

EFFECT OF HOT-WATER DIPS ON ENZYME ACTIVITY IN THOMPSON SEEDLESS GRAPES

Temperature of dip, degrees Fahrenheit	Dipping period, seconds	Per cent of light transmission	Log 1/T values for enzyme activity	Per cent increase or decrease in oxidase activity
180.....	{ 5.....	45.1	-0.345	+18.0
	{ 30.....	69.0	-0.162	-43.0
	{ 60.....	88.2	-0.092	-70.5
No dip (check).....		52.0	-0.284	..
205.....	{ 5.....	48.2	-0.315	+17.5
	{ 30.....	95.2	-0.020	-92.5
	{ 60.....	98.2	-0.006	-98.5
No dip (check).....		54.0	-0.268	....

water at 82.2° C (180° F) and 96.1° C (203° F). The results were very similar to those obtained in the experiments with the soda and mixed dips. Grapes dipped for 5 seconds in hot water at 82.2° C (180° F) and 96.1° C (203° F) displayed an increase in enzyme activity similar to that observed in the mixed-dip and soda-dip experiments. When grapes were subjected to the hot-water treatments for 30 or 60 seconds, on the other hand, enzyme activity decreased greatly as indicated in table 2. The skins of most of the grapes subjected to the soda dip, the mixed dip or the 30- and 60-second hot-water dips cracked extensively. The most severe skin cracking occurred when the longest dipping periods were used; the skins of grapes subjected to the 5-second hot-water dip, did not crack. When a grape oxidase preparation was heated for various periods of time at 82.2° C (180° F) and 95° C (203° F) no activation effect was observed (table 3). The enzyme system was almost completely inactivated in 30 seconds. This indicates that the apparently increased activity, observed when grapes were treated in the soda and the mixed dips for short periods of time, was due to some other cause than oxidase

response alone. Further tests were conducted with Muscat grapes which are larger and have thicker skins than the Thompson Seedless variety. Although the Muscat grapes were dipped in water at 95° C (203° F) for various periods of time up to 60 seconds, in no case did the skins of these grapes show cracking. Furthermore, the data obtained (table 4) show that heating in water for very short periods of time did not increase

TABLE 3
EFFECT OF HEAT ON THE ENZYME PREPARATION OBTAINED FROM
THOMPSON SEEDLESS GRAPES

Heating period in seconds at 180° F	Per cent of light transmission	Log 1/T values for enzyme activity	Per cent decrease in oxidase activity
0 (check).....	88.00	-0.056	..
2	88.50	-0.054	3.5
5	89.25	-0.050	8.9
10	88.50	-0.054	3.5
15	89.50	-0.046	17.6
20	95.00	-0.022	60.7
30	98.75	-0.005	91.1

TABLE 4
THE EFFECT OF HOT-WATER DIPS ON ENZYME ACTIVITY
IN MUSCAT GRAPES

Dipping period in seconds at 203° F	Per cent of light transmission	Log 1/T values for enzyme activity	Per cent decrease in oxidase activity
0 (check).....	39.0	-0.409	..
5	47.2	-0.323	22.0
10	86.0	-0.065	84.0
20	91.2	-0.039	90.7
60	95.2	-0.022	94.2

enzyme activity. The enzyme system was almost completely inactivated after 60 seconds of heating. This indicates that skin differences between the two varieties may be partially responsible for the variations in oxidase responses to the dipping treatments of short duration. Variations in oxidase distribution within the individual berry, as well as varietal differences in size of the berries, may also be factors accounting for the observed differences in effects of the heated dips on the oxidase activity of the two varieties.

In order to compare the distribution of enzyme activity in Thompson Seedless and Muscat grapes, individual berries were peeled and the Muscats were seeded. Table 5 shows that enzyme activity was greater

in the skins than in the flesh of the two varieties of grapes used. A much greater difference between enzyme activity in skin and flesh was observed in the Thompson Seedless than in the Muscat grapes. Enzyme activity in Muscat grapes was slightly greater in the skin than in the flesh. In Thompson Seedless, on the other hand, enzyme activity in the skins was over 31 times as great as that in the flesh. The skins of Thompson Seedless grapes showed more activity than either the skin or the flesh of Muscat grapes. The flesh of the former, however, showed less activity than either the skin or flesh of the latter. The relative richness in oxidase of skin as observed here agrees with the data of Hussein and Cruess

TABLE 5
COMPARISON OF ENZYME ACTIVITY OF SKIN AND FLESH OF THOMPSON
SEEDLESS AND MUSCAT GRAPES

Variety of grape	Portion of grape tested	Per cent of light transmission	Log 1/T values for enzyme activity	Weight ratio of skin to flesh	Oxidase activity ratio of skin to flesh*
Thompson Seedless	{ Skin.....	61.00	-0.215	0 113:1	31.1:1
	{ Flesh.....	82.50	-0.083		
Muscat.....	{ Skin.....	76.25	-0.118	0 101:1	7.75:1
	{ Flesh.....	75.00	-0.122		

* Solutions used in measurement of enzyme activity of Thompson Seedless skins were diluted twelve times and that for Muscat skins eight times. Corrected values for activity ratio of skin to flesh are given in the last column. The activity ratio of Muscat flesh to Thompson Seedless flesh (corrected value) = 1.47:1; and of Muscat skin to Thompson Seedless skin (corrected value) = 0.37:1.

(1940) concerning the location of the enzyme in the grape. This observed unequal enzyme distribution is probably concerned, to some extent at least, with the variations in enzyme responses when Thompson Seedless and Muscat grapes were treated in the hot-water dips. It may also account for the fact that Muscat grapes that retain a light color have not been produced successfully on a commercial scale by use of the cold, mixed, or soda dips without a subsequent sulfuring treatment.

Effect of Sulfuring.—Sulfur-bleached raisins were dried to a moisture content of about 15 per cent. The oxidase activity in finished raisins varied greatly with the period of exposure and concentration of SO₂ used in the sulfuring treatment. The data in table 6 show that the enzyme activity in the sulfur-bleached raisins decreased with increase in length of the sulfuring period. In these experiments, as in commercial practice, the lightest-colored raisins were obtained when grapes were sulfured for 2 hours and the darkest when they were sulfured for 1 hour or less. Table 7 indicates that the concentration of SO₂ in the sulfuring house at the time of sulfuring also affects the enzyme activity of raisins treated by this method.

Raisins prepared by drying grapes sulfured at the higher concentrations of SO_2 , for a given period of time had less enzyme activity than those sulfured at lower concentrations for the same period of time. Apparently the time of exposure and concentration of SO_2 during sulfuring are both important in diminishing oxidase activity in sulfured raisins. Hussein and Cruess (1940) found that very high concentrations of SO_2

TABLE 6
EFFECT OF TIME OF SULFURING ON THE OXIDASE ACTIVITY
OF SULFUR-BLEACHED RAISINS

Sulfuring period, minutes*	SO_2 in raisins, p.p.m.	Log 1/T values for enzyme activity†	Per cent decrease in oxidase activity	Color grade of the finished raisins‡
0 (check)	...	-0.025	...	Poor
30	150	-0.023	7.0	Poor
60	300	-0.016	35.7	Poor
90	400	-0.010	59.5	Fair
120	570	-0.005	79.4	Good

* The concentration of SO_2 in the sulfuring compartment was 1.5 per cent by volume, and the temperature, 105° – 120° F.

† Represents activity calculated to 1 gram of dry weight.

‡ Color grade judged from standpoint of salability as sulfur-bleached raisins.

TABLE 7
EFFECT OF CONCENTRATION OF SO_2 DURING SULFURING ON THE OXIDASE
ACTIVITY OF SULFUR-BLEACHED RAISINS

Concentration of SO_2 in per cent by volume in sulfuring compartment*	SO_2 in raisins, p.p.m.	Log 1/T values for enzyme activity†	Per cent decrease in oxidase activity	Color grade of the finished raisins‡
Check	...	-0.025	...	Poor
0.75	270	-0.020	18.7	Poor
1.50	570	-0.006	77.9	Good

* The length of the sulfuring period was 120 minutes and the temperature 105° – 120° F.

† Represents activity calculated to 1 gram of dry weight.

‡ Color grade judged from standpoint of salability as sulfur-bleached raisins.

were required to inactivate a grape-enzyme preparation. Oxidase activity decreased gradually as the concentration of SO_2 added to the solution was increased from 0 to 5,580 p.p.m., but was not entirely inhibited at any concentration used. It is difficult to understand why the enzyme preparation should be so resistant to SO_2 . Possibly other factors such as physical condition of the grapes, maturity, and temperature complicate the results.

Effect of Drying.—The treatment of grapes preliminary to drying is the same for golden-bleached and sulfur-bleached raisins. Both are lye-dipped and sulfured; but the former are then dehydrated and the

latter are exposed to the sun for a short time and later dried in the shade. The two products, however, are different in appearance and storage qualities. Sulfur-bleached raisins usually darken more rapidly in storage than do the golden-bleached; this may be attributed to some extent to the higher moisture content in the former. Nevertheless it was thought that oxidase may play a part in this darkening. Consequently, grapes from each of two lots were dehydrated and shade-dried and then compared for oxidase activity. Table 8 shows that the enzyme activity in the

TABLE 8
EFFECT OF SUN-DRYING AND DEHYDRATION ON OXIDASE ACTIVITY
IN THE DRIED PRODUCTS

Drying procedure	Per cent of light transmission	Log 1/T values for enzyme activity	Ratio of activity of dehydrated to sun-dried
Dehydrated at 160° F.	90.75	-0.042	0.188:1
In sun 1 day and then dried in the shade.	59.75	-0.224	
Dehydrated at 160° F.	88.75	-0.052	0.213:1
In sun 1 day and then dried in the shade.	57.00	-0.244	

dehydrated product was approximately one fifth of that of shade-dried. This variation in oxidase activity may account for some of the differences in the storage qualities of the two types of raisins.

SUMMARY

Oxidase enzymes cause discoloration of grapes and raisins under certain conditions. Experiments have been conducted to determine the effect of various dipping, sulfuring, and drying procedures on this activity. The commercial cold-, mixed-, and soda-dip treatments decreased the oxidase activity when immersion periods of sufficient length were used. Oxidase activity was stimulated by very short, soda, mixed, and hot-water dips. Sulfuring decreased the oxidase activity, approximately in proportion to the period of exposure and concentration of SO_2 used during sulfuring. Raisins prepared by dehydration had about one fifth the oxidase activity of sulfured grapes dried in the shade, probably because of the relatively high temperature used for dehydration.

The diminishing effect on oxidase activity of some of the commercial dipping treatments may account for the production of light-colored raisins without the use of SO_2 .

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**SOME FACTORS AFFECTING THE BURNING
OF SULFURS USED IN SULFURING
FRUITS**

C. S. BISSON, H. W. ALLINGER, AND H. A. YOUNG

SOME FACTORS AFFECTING THE BURNING OF SULFURS USED IN SULFURING FRUITS¹

C. S. BISSON,² H. W. ALLINGER,³ AND H. A. YOUNG⁴

DURING THE 1936 season, growers in various districts in California were experiencing some difficulty in sulfuring the fruit to be dried. Long, Mrak, and Fisher⁵ found that the difficulties of that season were merely a recurrence of a series of yearly troubles. These investigators determined that some of the samples of sulfur in question burned 90 to 100

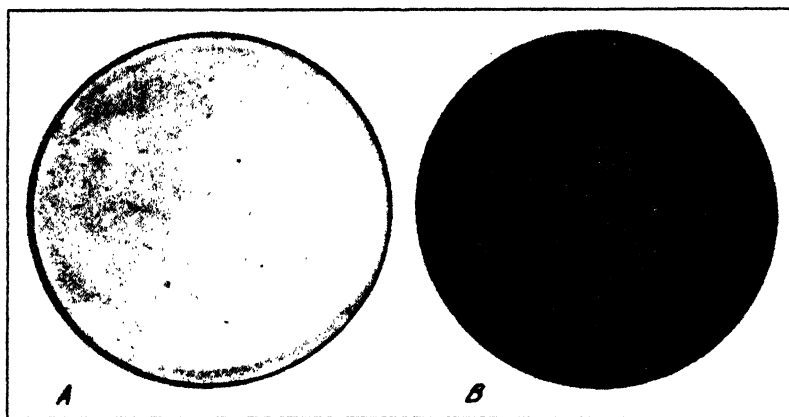


Fig. 1.—Illustrations of slag resulting from incomplete burning: *A*, light-colored slag from a high-grade sulfur indicating that the fire was smothered through insufficient ventilation; *B*, dark-colored slag from a low-grade sulfur indicating that the fire was smothered by carbon or carbonaceous matter which floated to the surface of the molten sulfur.

per cent, whereas many others burned anywhere from 10 to 50 per cent. With the poor-burning sulfurs the result was reduced quality of the product, delay in operations during the drying season, and an actual loss of sulfur through failure to burn.

Poor-burning sulfurs develop, over the burning, molten surface, a black film that decreases the rate of vaporization of the sulfur by shielding the molten sulfur from direct contact with the flame, which grad-

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⁵ Long, J. D., E. M. Mrak, and C. D. Fisher. Investigations in the sulfuring of fruits for drying. California Agr. Exp. Sta. Bul. 636:1-56. 1940.

ually decreases the burning area and finally extinguishes the flame. The unburned sulfur solidifies on cooling and forms a dark hard cake or slag (fig. 1), not easily removed from the pans.

Though a black variety of sulfur can be produced,* the sulfur samples tested in the experiments reported here were not subjected to the same conditions as those given for producing the black variety.

EXPERIMENTAL RESULTS

Identification of Contaminants Affecting Burning.—Chemical tests on the composition of this black film on cakes from commercial sulfuring houses showed, after the included sulfur had been driven off by controlled heat treatment, that the film consisted largely of carbon or carbonaceous material, with some siliceous matter and iron oxide, the second probably coming from dust, and the latter chiefly from the iron pans in which the sulfur was burned by the growers.

When this work was first undertaken it was planned to be carried out entirely in the laboratory. The results obtained were such, however, that it was decided to follow up the laboratory experiments with field tests conducted in a commercial sulfuring house. All of the sulfurs used in the following experiments were of commercial grade and of unknown purity.

Laboratory Experiments.—Tests were directed toward investigating the role that the impurities found in the black film or scum play in reducing the burning of sulfurs. The method consisted in adding varying small amounts of iron oxide, siliceous compounds, and carbonaceous matter to samples of sulfur no. 1 that normally burned 99.7 per cent, and observing how these added materials affected the reduction of the amount of sulfur burned.

In working out the procedure to be followed in these tests, it was found that the methods adopted would be empirical. That is, the results would depend considerably on factors influencing the temperature of the sulfur and the film formation—for example, the size of the sample used; the control of air drafts; the size, shape, and composition of the container; and the nature of the surface on which the container was placed (transite, wood, sand, and the like).

In a series of tests, 10-gram samples of sulfur gave the most consistent results. These tests also showed that 2.5-inch porcelain evaporating dishes are more satisfactory than 2-inch straight-sided aluminum dishes for the burning of sulfur. Transite board proved to be the most satis-

* Mellor, J. W. A comprehensive treatise on inorganic and theoretical chemistry. Vol. 10, p. 34. Longmans, Green and Company, New York, N. Y. 1930.

factory support for the sulfur dishes. Careful shielding of the containers was necessary to insure consistently good burning.

All samples were burned from a cold start (except where noted) under optimum conditions. That is, the cold sulfur was carefully lighted with

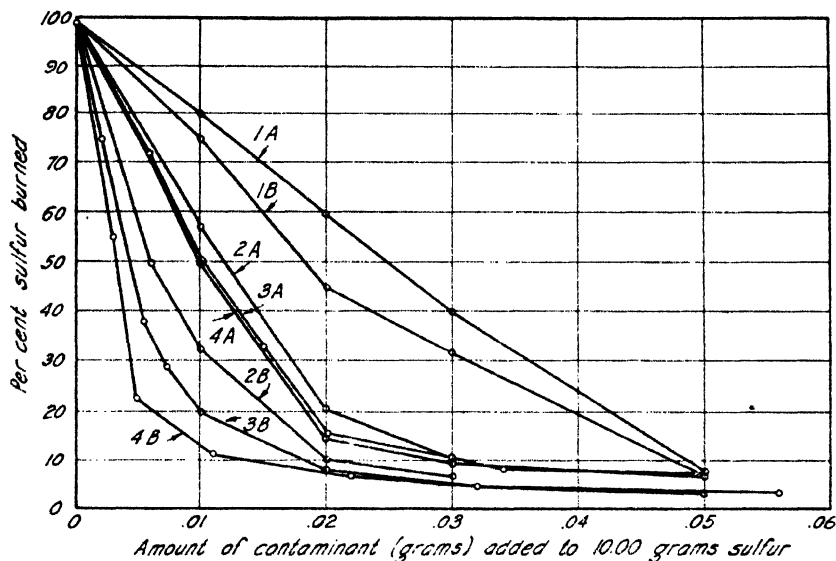


Fig. 2.—Effect of lubricating oil (medium) and of fuel oil on the percentage of sulfur burned:

Curve 1A, fuel oil added; burned at once without mixing.

Curve 2A, fuel oil added; burned after one thorough mixing.

Curve 3A, fuel oil added; burned after 4 hours and three thorough mixings during the interval.

Curve 4A, fuel oil added; burned after 24 hours and four thorough mixings during the interval.

Curve 1B, lubricating oil added; burned at once without mixing.

Curve 2B, lubricating oil added; burned after one thorough mixing.

Curve 3B, lubricating oil added; burned after 4 hours and three thorough mixings during the interval.

Curve 4B, lubricating oil added; burned after 24 hours and four thorough mixings during the interval.

a match, the match discarded, and the dish then placed on a transite board and shielded from drafts.

Effect of Various Admixtures on Burning.—In the first experiments on the effect of impurities on sulfur burning, small amounts of ignited dust or iron oxide, varying from 0.005 to 0.05 gram, were mixed with 10-gram samples of sulfur no. 1, and the mixtures burned. These contaminants in the quantities used did not significantly affect the burning of the sulfur. Judging from these results, tests would have to be confined

to a study of the difficulty originating from the presence of carbonaceous matter in commercial sulfurs.

In order to determine how molten sulfur affects the volatile vapors of carbon compounds, hot vapors from boiling fuel oils were bubbled through hot molten sulfur in a test tube. The sulfur darkened quickly;

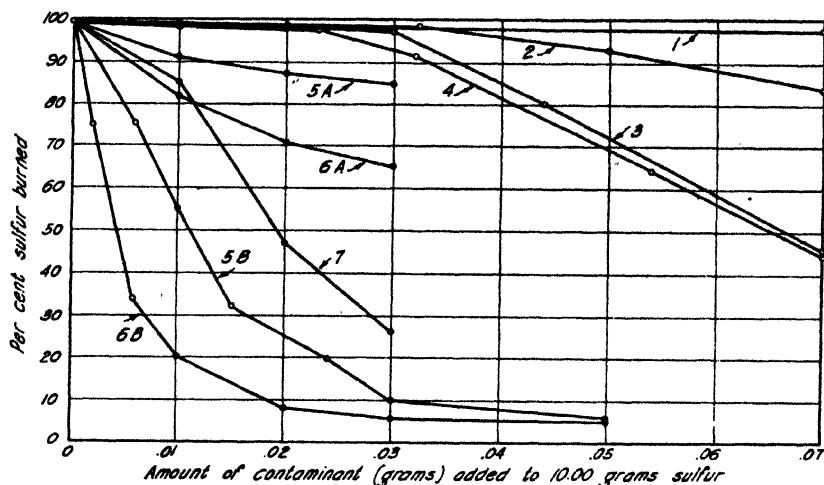


Fig. 3.—Effect of sack lining, burlap sacking, newspaper, sawdust, linseed oil, and rosin on the percentage of sulfur burned:

Curve 1, sack lining added (finely cut); burned after 1 hour with one thorough mixing.

Curve 2, burlap sacking added (finely cut); burned after 1 hour with one thorough mixing.

Curve 3, newspaper, added (finely cut); burned after 1 hour with one thorough mixing.

Curve 4, sawdust added; burned after 1 hour with one thorough mixing.

Curve 5A, linseed oil added; burned at once without mixing.

Curve 5B, linseed oil added; burned after 4 hours with three thorough mixings during the interval.

Curve 6A, rosin dust added; burned at once without mixing.

Curve 6B, rosin dust added; burned after 4 hours with three thorough mixings during the interval.

Curve 7, paraffin added (finely cut); mixed in, and burned after 3 hours.

and a black film was formed over the sulfur and on the sides of the test tube above the sulfur, clearly indicating the breakdown of the fuel-oil vapors in their passage through the hot sulfur. With these results as a basis, various types of materials (lubricating oil, fuel oil, kerosene, gasoline, linseed oil, turpentine, rosin, organic acids, sawdust, paper scraps, sacking, and the like) were added to 10-gram samples of sulfur no. 1, and the resulting mixtures were burned. Some of these mixtures were burned immediately without mixing, whereas others were mixed and allowed to stand as described in figures 2 to 4.

Figure 2 shows the effect of adding varying amounts of lubricating oil (medium) and fuel oil to sulfur no. 1. As the curves show, the more thoroughly the added materials are mixed with the sulfur and the longer the time allowed for diffusion of the added substances, the lower is the percentage of sulfur burned; the greatest decrease occurred in mixtures

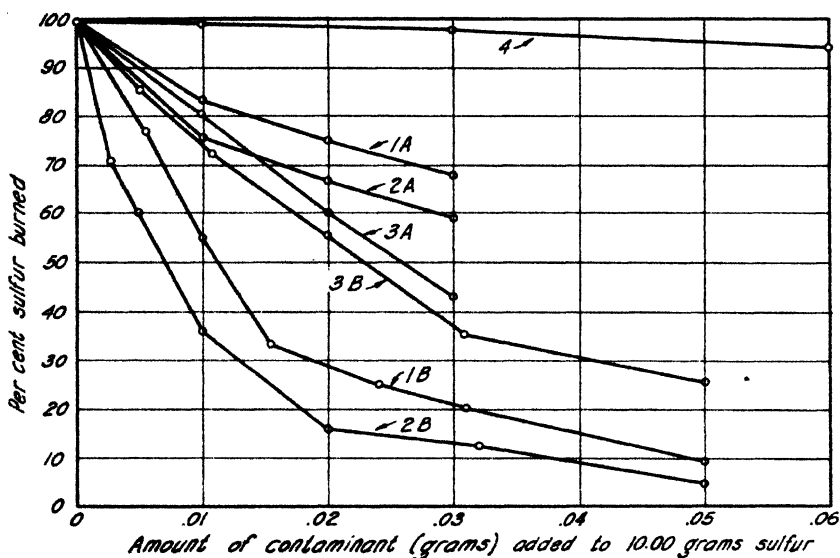


Fig. 4.—Effect of gasoline, turpentine, oleic acid, and stearic acid on the percentage of sulfur burned:

Curve 1A, stearic acid added; burned at once without mixing.

Curve 1B, stearic acid added; burned after 4 hours and after three thorough mixings during the interval.

Curve 2A, oleic acid added; burned at once without mixing.

Curve 2B, oleic acid added; burned after 4 hours and after three thorough mixings during the interval.

Curve 3A, turpentine added; burned at once without mixing.

Curve 3B, turpentine added; burned after 4 hours and three thorough mixings during the interval.

Curve 4, gasoline added; burned after 2 hours and two thorough mixings during the interval.

where the weight of the added impurity was less than 0.01 gram. The slope of the curve gradually decreased when amounts up to 0.05 gram were added. In appearance and in effect on burning, the film or scum formed by these materials resembles that observed when low-grade commercial sulfurs were burned.

Figure 3 manifests a marked difference in the effect of certain added materials on the reduction of the percentage of sulfur burned. The curves for linseed oil and rosin show much the same slope as the oils in figure 2.

They show the same large initial drop in percentage of sulfur burned when very small amounts are added and well mixed in, and a much smaller drop when larger amounts up to 0.05 gram are added.

The picture is very different for the other materials in figure 3—when sack lining, newspaper scraps, burlap sacking, and sawdust are added. Sack lining, used by some sulfur companies to line burlap sacks for the better protection of their product, had very little effect on the burning

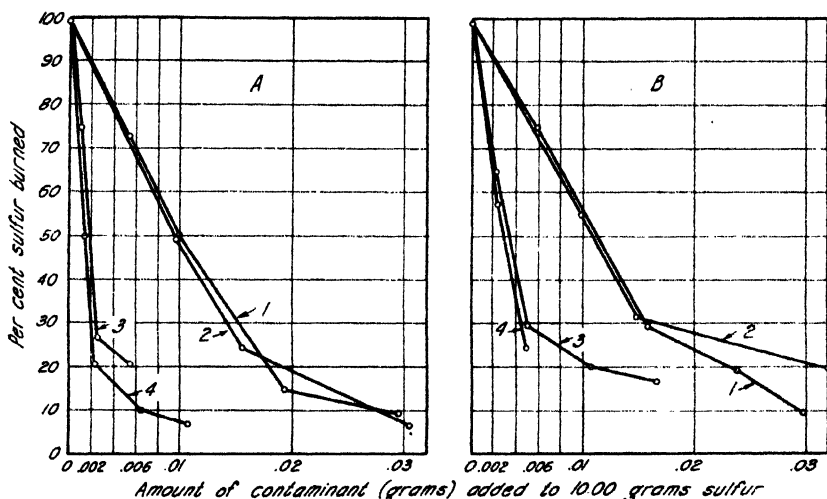


Fig. 5.—A, Effect of fuel oil on the percentage of sulfur burned:

Curve 1, laboratory test, in 1938, with sulfur no. 1.
 Curve 2, laboratory test, in 1940, with sulfur no. 6. Same treatment as in 1938.
 Curves 3, 4, field test, in 1940; four thorough mixings, and let stand overnight.

B, Effect of linseed oil on the percentage of sulfur burned:

Curve 1, laboratory test, in 1938, with sulfur no. 1.
 Curve 2, laboratory test, in 1940, with sulfur no. 6. Same treatment as in 1938.
 Curves 3, 4, field test, in 1940; four thorough mixings, and let stand overnight.

of sulfur when added in finely divided amounts up to 0.07 gram. Newspaper scraps, sawdust, and burlap lowered the percentage of sulfur burned very little when present in amounts less than 0.03 gram; but in larger amounts, up to 0.07 gram, they reduced the amount of sulfur burned to about one half. Since sugar had practically no effect on the burning of sulfur, its curve is not given in the figure.

Figure 4 shows the effect of stearic acid, oleic acid, turpentine, and gasoline in unmixed and thoroughly mixed samples. The unsaturated acid, oleic, shows the largest reduction in the amount of sulfur burned. The test with gasoline affected the burning of sulfur very little, probably because of its high volatility.

Field Experiments.—The laboratory experiments furnished striking data on the deleterious effect of small amounts of certain carbon and carbonaceous material on the burning qualities of sulfur. The next step in this work was to learn how data obtained under laboratory conditions checked with those secured under field conditions, where large quantities of sulfur (4 or more pounds) are burned in commercial sulfuring houses. Accordingly a three-compartment sulfuring house⁷ on the Davis campus

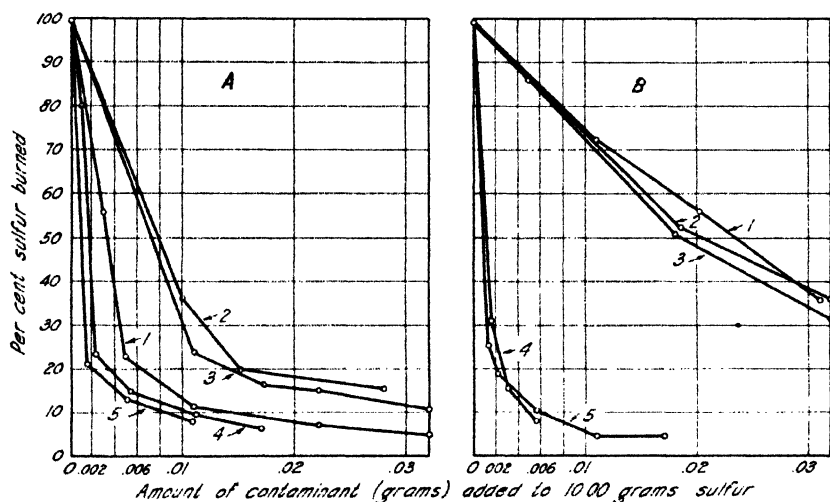


Fig. 6.—A, Effect of lubricating oil on the percentage of sulfur burned:

Curve 1, laboratory test, in 1938, with sulfur no. 1.

Curves 2, 3, laboratory test, in 1940, with sulfur no. 6. Same treatment as in 1938.

Curves 4, 5, field test, in 1940; four thorough mixings, and let stand overnight.

B, Effect of turpentine on the percentage of sulfur burned:

Curve 1, laboratory test, in 1938, with sulfur no. 1.

Curves 2, 3, laboratory test, in 1940, with sulfur no. 6. Same treatment as in 1938.

Curves 4, 5, field test, in 1940; four thorough mixings, and let stand overnight.

was used for these tests. A high-grade sulfur (no. 6), which burned 99.75 per cent, was used as a base to which were added varying amounts of lubricating oil, fuel oil, linseed oil, turpentine, newspaper, sawdust, and burlap sacking. Since in the 1938 laboratory work sulfur no. 1 was used, some laboratory tests on sulfur no. 6 were made for comparison. The amount of sulfur used in each of the field trials was 1,800 grams (nearly 4 pounds). These samples were burned in clean metal pans in an empty sulfuring compartment.

To facilitate comparison between the laboratory and field results, the

⁷ This sulfuring house was constructed according to the design by Long, Catlin, and Nichols, given in California Agricultural Extension Service Farm Building Plan C-173, 1934.

latter data were recalculated to fit the scale used in the graphs of the 1938 laboratory experiments. Figures 5 to 7 show the data in this form.

The effect of contaminants on burning were on the whole greater in the field than in the laboratory. As figure 5, *A*, shows, approximately a

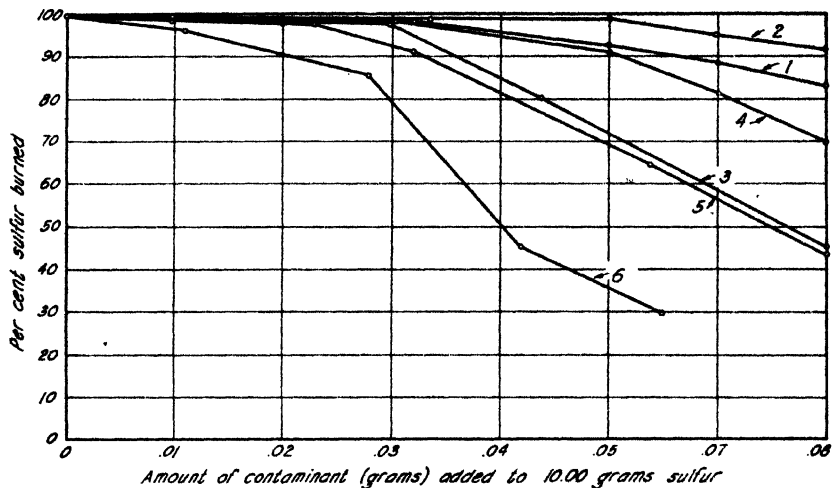


Fig. 7.—Effect of burlap sacking, newspaper, and sawdust on the percentage of sulfur burned:

- Curve 1, burlap sacking added. Laboratory test, in 1938, with sulfur no. 1.
- Curve 2, burlap sacking added. Field test, in 1940, with sulfur no. 6.
- Curve 3, newspaper cuttings added. Laboratory test, in 1938, with sulfur no. 1.
- Curve 4, newspaper cuttings added. Field test, in 1940, with sulfur no. 6.
- Curve 5, sawdust added. Laboratory test, in 1938, with sulfur no. 1.
- Curve 6, sawdust added. Field test, in 1940, with sulfur no. 6.

50 per cent reduction in the burning of sulfur was caused by 0.01 gram fuel oil in the laboratory tests, whereas in the field only 0.0014 gram (one seventh as much) was needed to produce the same reduction. In figure 5, *B*, 0.016 gram linseed oil lowered burning to about 30 per cent in the laboratory, while in the field 0.0052 gram reduced the burning to 24–29 per cent in two series of trials. Still more striking were the tests with turpentine in figure 6, *B*. With 0.02 gram turpentine in the laboratory, sulfur burned approximately 55 per cent; but in the field only 0.001 gram (one twentieth as much) was needed to bring about a similar reduction. Lubricating oil in figure 6, *A*, does not show so great a difference between the 1938 laboratory tests and the 1940 field results. With 0.0048 gram lubricating oil, sulfur burned 22.5 per cent in the laboratory; and in the field 0.0014 gram produced the same result. The curves obtained in the 1938 and the 1940 laboratory tests for lubricating oil do not check as they do for fuel oil, linseed oil, and turpentine. This dif-

ference may be caused by a somewhat different grade of lubricating oil used in 1940. If the 1940 data are used for comparison, the difference between laboratory and field results is greatly increased.

In figure 7, sawdust in the field experiments reduced the burning of sulfur much more than it did in the laboratory. This is not the case with newspaper cuttings and burlap sacking, whose field curves lie above those of the laboratory. No satisfactory explanation was found for this reversal.

In the field the sulfur is burned in an enclosed chamber where the air intake is greatly reduced and the sulfur dioxide gas accumulates to a large extent, whereas in the laboratory the sulfur is burned in the open with free access to air and with no accumulation of gases. This difference in burning conditions perhaps explains the greater reduction of contaminated sulfur burned in the field experiments.

Sources of Contamination.—As for the sources of contamination of sulfurs in actual practice, the contaminants may be matches, rags, or papers dropped carelessly into the sulfur after igniting it; from admixture with impure slag in the burners from pervious burnings; from oily floors on which the sacks of sulfur may have been stored; or from burlap sacks containing some oily matter. In the two last-mentioned instances such contaminating materials will penetrate the sulfur in the sacks by diffusion and reduce the percentage of sulfur that will burn freely.

Experiments (made in 1938) in which samples of sulfur no. 1 were placed in the vapors arising from the surface of heavy diesel fuel oil held at room temperature (25° C or 77° F) showed, in every case, a noticeable increase in black film formation and a decrease in the percentage of sulfur burned when compared with that of the original sulfur sample. One sample stored for 6 days over the fuel oil showed a decrease of 9 per cent in the percentage of sulfur burned. These results indicate that the oil vapor is absorbed by the sulfur at ordinary temperatures.

Another source of contamination may go back to the origin and preparation of the sulfur. In the preparation, traces of hydrocarbon oils may be introduced from pipes used to convey steam and from contamination by traces of oil from contiguous strata. Several fractional distillations^{*} are required to remove the last traces of hydrocarbons from sulfur during preparation or refining.

This investigation did not aim to determine whether the carbonaceous matter in poor-burning commercial sulfurs is caused by insufficient refining, subsequent contamination, or both.

Purification of Contaminated Sulfur.—A method for freeing sulfur from interfering contaminants consists in heating the crude sulfur under

^{*} See page 19 of citation given in footnote 6.

pressure over a temperature range of 255° to 320° C for a sufficient period to complete the chemical reactions. The excess sulfur is then sublimed from the residue.

Tests were made with solvents to ascertain whether contaminating materials could be removed by extraction. As table 1 shows, the solvent action of ethyl ether was somewhat better than that of petroleum ether on the impurities in the sulfur. Commercial sulfur no. 4 normally burned 39.0 per cent; but when extracted with petroleum ether it burned 83.7 per cent, and with ethyl ether, 89.5 per cent. The next greatest effect was with no. 5, which burned 61.0, 82.4, and 91.2 per cent, respectively.

TABLE 1
PERCENTAGE OF SULFUR BURNED BEFORE AND AFTER THREE-HOUR
EXTRACTION OF TEN-GRAM SAMPLES WITH SOLVENTS

Sulfur no.	Before extraction	After extraction	
		With petroleum ether	With ethyl ether
2.....	74.0	84.5	90.5
3.....	70.0	91.0	92.2
4.....	39.0	83.7	89.5
5.....	61.0	82.4	91.5

Extractions with methylene chloride and ethylene chloride were not successful; 20 to 25 per cent of the sulfur dissolved, and difficulty was also experienced in removing the last traces of the solvents from the undissolved sulfur.

Extraction of poor-burning sulfurs with petroleum and ethyl ethers increased the percentage of sulfur burned up to 90 per cent or above; but the volatility and inflammability of these solvents and the difficulty of their complete removal from the treated sulfur makes this treatment non-feasible for growers as a means of purifying sulfur.

Effect of High Temperature on Poor-burning Sulfurs.—Another method of increasing the burning quality of low-grade sulfurs has more promise. As stated before, scum formation decreases the burning area, lowers the temperature of the molten sulfur, and causes the flame to die out. To study the effect of maintaining the temperatures of the dishes containing the burning sulfur at higher levels, samples of medium-burning and poor-burning commercial sulfurs were placed in a sandbath; and the bath was heated to 300° C (572° F) and maintained at that temperature after igniting the sulfurs. The results are given in table 2. In all cases the percentage burned was increased. Judging from these tests, if the temperature of the pans containing poor-burning sulfurs can be

maintained at about 200° C, these sulfurs will burn almost completely. Even at 150° C sulfurs nos. 2 and 3 burned 98.1 and 99.6 per cent (table 2). Preventing or minimizing the loss of heat from the pans is definitely indicated. Some growers have placed asbestos or other insulating material around the sulfur pans, and thereby obtained some measure of success in increasing the amount of sulfur burned. Application of heat

TABLE 2
EFFECT OF RAISING TEMPERATURE OF SULFUR ON PERCENTAGE BURNED

Sulfur no.	Room temperature 25°-30° C	Sandbath maintained at		
		300° C	200° C	150° C
2.....	74 0	99 9	99 6	99 6
3.....	70 0	99 9	99 7	98 1
7.....	34 8	99 9	99 6	96 2
8.....	34 0	99 9	99 7	96 5

to the sulfur containers by a regenerative heating process holds some promise of usefulness, but this process requires careful control of the amount of air used to burn the sulfur completely.

SUMMARY

As chemical tests showed, the black film consisted almost entirely of carbon or carbonaceous material, with small amounts of siliceous matter and iron compounds.

Small amounts of inorganic materials such as dust and iron oxide have practically no effect on reducing the percentage of sulfur burned.

Judging from experiments on black-film formation, carbon or carbonaceous matter originated most likely from the interaction of molten sulfur or hot sulfur vapors, with traces of certain organic impurities. Of the widely varying materials tested, the petroleum oils and turpentine produced the most pronounced effect on film production and also showed the greatest reduction of sulfur burned, whereas cellulose materials had the least effect.

Under field conditions the percentage of burning of contaminated sulfur was considerably less than in the laboratory. This decrease in combustibility was probably due to the limited access of air and the accumulation of sulfur dioxide in the sulfur chamber.

Extracting or washing poor-burning sulfurs with suitable solvents was found to increase the percentage of sulfur burned, but this method is not economical in farm practice.

Samples of sulfur stored 2 to 6 days in an atmosphere of vapors arising from fuel oil were found to absorb sufficient amounts of volatile carbon compounds to increase the black-film formation and decrease the amount of sulfur burned. This fact may be important in defining proper conditions for the storage of sulfur.

Raising the temperature of the sulfur container will almost completely burn a contaminated sulfur.

MEASUREMENTS ON HYDROCYANIC ACID ABSORBED BY CITRUS TISSUES DURING FUMIGATION^{1,2}

E. T. BARTHOLOMEW,³ WALTON B. SINCLAIR,⁴
AND D. L. LINDGREN⁵

METHODS FOR the accurate determination of hydrocyanic acid (HCN) and studies of factors affecting the recovery of HCN from fumigated citrus tissues have been previously reported (1, 2).⁶ The present paper is concerned with the results of the application of the principles derived from the earlier studies to further laboratory experiments, performed in conjunction with the fumigation studies of citrus trees under orchard conditions.

The effect of certain factors, such as oil sprays, the locality in which the trees were grown, and the temperature, age, and moisture content of citrus tissues at time of fumigation, have been studied in relation to the absorption and retention of HCN under both laboratory and field conditions. The comparative amounts of absorption and lengths of time of retention of HCN have also been studied in relation to maturity of leaves and fruits and in relation to their injurious or noninjurious effects. The results of laboratory experiments cannot always be applied directly to the solution of orchard fumigation problems, but they may serve as a basis for the formulation of field experiments.

The trees, leaves, and fruits used in the experiments described in this paper were of the Valencia-orange variety (*Citrus sinensis* Osbeck).

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⁶ Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

MATERIALS AND METHODS

The leaves used in these experiments were mature. The fruits were of different ages, but in most cases in this paper are referred to as either "green" or "mature." The term "green" refers to the color of the fruit; green fruits were always immature. Valencia oranges in California usually become orange yellow in color before they mature. A few fruits of this kind were used and are referred to as "immature yellow." The approximate age of the fruits in the different samples is indicated by the specifications given in connection with the tables and figures.

In the first of these experiments, the paired samples contained the same number of fruits, each fruit had approximately the same equatorial diameter, and each of the samples weighed approximately the same. The amounts of HCN recovered from these fruits were expressed as total recovery per sample. In the later experiments, the total surface area of the fruit in each sample was also determined, and the amounts of HCN recovered were then expressed in milligrams per unit of fruit surface.

At the end of the fumigation period, the fruits (both peel and pulp) in each sample were cut into 12 to 25 small pieces, the number of pieces depending upon the size of the fruit. These pieces were then placed in a distillation flask. When leaves were used, they were placed whole in the distillation flask. The distillations were made as already described in a previous report (2).

In one experiment, trees in the field were sprayed with oil, and samples of leaves and fruits from the sprayed trees, together with similar samples from unsprayed trees, were then brought to the laboratory and fumigated to determine the comparative amounts of HCN that each would absorb.

The Fumigation of Citrus Leaves and Fruits in the Laboratory.—When the leaf and fruit samples were brought to the laboratory, they were fumigated in a gastight metal fumatorium having a capacity of 100 cubic feet. This capacity was sufficient to make possible the fumigation of many samples at one time, which was often necessary during these investigations. At each fumigation, 8 ml of liquid HCN of at least 96 per cent purity was used in the fumatorium. (This amount of HCN for each 100 cubic feet in a gastight metal fumatorium in the laboratory has been found to be as effective for killing scale insects as 20 ml for each 100 cubic feet in a more or less porous tent in the field.) The liquid HCN was vaporized before it was forced into the fumatorium, where the air was kept in continuous motion by means of an electric fan. Unless otherwise stated, all fumigations were made at 75° F. The samples remained in the fumatorium for 40 minutes.

The Fumigation of Citrus Trees in the Field.—In the field, trees were fumigated at night or during the day and under different environmental conditions to determine the comparative amounts of HCN absorbed by leaves and fruits and the comparative lengths of time required for disappearance of the HCN from the tissues. The trees were fumigated by the usual commercial method (9). Each tree was covered with a canvas tent, and heated liquid HCN was vaporized into the tent near the bottom center of the tree. A 20-ml schedule (20 ml of liquid HCN per unit¹ of tree space) was used for all trees except one, for which an 18-ml schedule was used. The fumigation period for the field work was 45 minutes.

At the end of the fumigation period, the tent was removed from the tree, and the first samples of leaves or fruits were picked at once. The leaf samples (200 grams each) were placed directly into distilling flasks and covered with distilled water. The flasks were then stoppered, shaken thoroughly, and brought to the laboratory, where the leaves were distilled to recover the HCN which they had absorbed. The samples of fruits were brought to the laboratory, weighed, measured, cut into small pieces, placed in distilling flasks, and distilled for HCN recovery. Subsequent samples of leaves and fruits were taken at intervals from the same trees until the tissues were free, or nearly free, of HCN.

CONCENTRATIONS OF HCN IN FUMATORIUM AND IN TENTS DURING FUMIGATION PERIODS

HCN Concentrations in Fumatorium.—The concentrations of HCN in the fumatorium during each fumigation period were determined on 2-liter samples of air withdrawn at intervals of 1, 3, 7, 15, 30, and 40 minutes after fumigation began. As the air samples were withdrawn from the fumatorium, they passed through an 0.1 *N* solution of NaOH, upon which the HCN determinations were made. During this experiment 936 such determinations were made. The results are too numerous to give in tabular form but are shown in the form of a broken-line curve in figure 1.

Each point on the curve (fig. 1) represents the mean of 156 determinations made at the time interval indicated. The mean for the determinations made at the 1-minute interval was 1.45 mg of HCN per liter of space in the fumatorium; that for determinations at the 40-minute interval was 1.33 mg, or only 8.3 per cent less. The concentration of HCN in the fumatorium therefore remained nearly constant during each 40-minute fumigation period.

HCN Concentrations in Tents.—The concentrations of HCN in the tents during each fumigation were determined in the same manner as

¹ A unit equals approximately 100 cubic feet of space under a tent covering an average-sized citrus tree such as the trees used in these experiments.

those in the fumatorium. Two-liter samples of air were drawn from near the center of each tent at the intervals shown in table 1, and their HCN content was determined. The concentration of HCN in each tent at the different sampling intervals is also shown in this table.

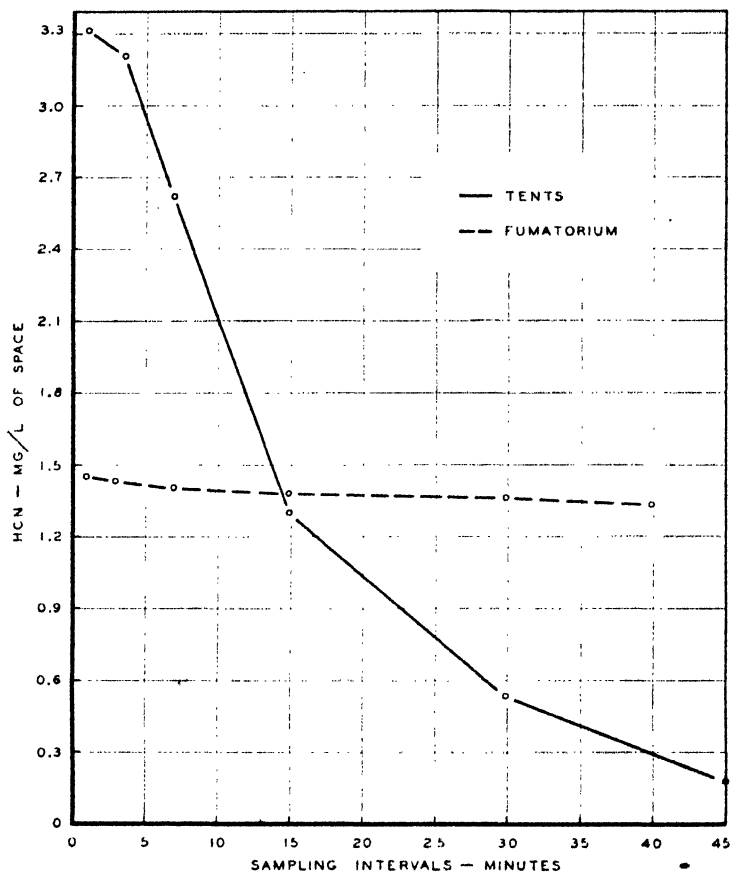


Fig. 1.—Average number of milligrams of HCN per liter of space under fumigation tents and in the fumatorium at given intervals during fumigation periods. The data for the tent curve were taken from table 1. Each point on the fumatorium curve represents the average of 156 determinations. The average fumigation dosage of liquid HCN for each 100 cubic feet of space was 20 ml under the tents and 8 ml in the laboratory fumatorium.

Although the initial amount of HCN forced under each tent was the same (20 ml per unit, except for tree 4, which was given only 18 ml), the amount to which each tree was exposed at different intervals during the fumigation period was noticeably different. These differences are shown by the HCN recoveries from the air samples taken at the given

intervals (table 1, cols. 1 to 8). Figures in column 1 of table 1 show very plainly that in several cases the HCN had not yet become distributed in the tent at the end of the 1-minute interval. Tent porosity, air temperature, humidity, and movement, and similar factors were no doubt responsible for this condition. The final concentrations at the end of the 45-minute fumigation periods (table 1, col. 8) ranged from 0.1 to

TABLE 1
CONCENTRATION OF GASEOUS HCN UNDER TENT, NEAR CENTER OF TREE,
AT DIFFERENT INTERVALS DURING FUMIGATION*

Tree no.	HCN per liter of space								
	After 1 minute	After 3 minutes	After 4 minutes	After 7 minutes	After 15 minutes	After 30 minutes	After 40 minutes	After 45 minutes	Mean†
	1	2	3	4	5	6	7	8	9
	mg	mg	mg	mg	mg	mg	mg	mg	mg
1.	0.6	...	2.2	1.9	1.0	0.4	0.2	...	0.9
2.	1.0	3.5	...	3.2	1.8	0.7	...	0.2	1.4
3.	3.1	...	4.8	3.4	1.7	0.6	...	0.2	1.6
4.	2.3	3.7	...	2.4	1.2	0.4	...	0.1	1.1
5.	2.8	3.7	...	2.7	1.2	0.5	0.2	...	1.3
6.	7.2	3.1	...	4.5	1.1	0.2	...	0.1	1.4
7.	9.8	3.5	...	1.9	1.8	0.9	...	0.2	1.6
8.	8.0	...	4.4	2.9	1.4	1.2	...	0.3	1.8
9.	0.3	...	2.3	2.1	1.2	0.4	...	0.2	0.9
10.	1.0	3.2	...	2.1	1.0	0.3	...	0.1	0.9
11.	0.5	1.5	...	2.0	1.1	0.5	...	0.2	0.9
12.	3.5	...	2.8	2.4	1.1	0.4	...	0.1	1.0
Mean....	3.3	3.2		2.6	1.3	0.5	0.2		1.2

* Trees 1 to 5 and 9 to 12 were fumigated at night, September 20 to November 14, 1939, and July 23 to August 15, 1940, respectively; trees 6 to 8 were fumigated in the daytime (trees 6 and 7 at 9:45 a.m. and tree 8 at 10:30 a.m.), July 23 to 29, 1940. The fumigation schedule was 20 ml per unit except for tree 4, which was given only 18 ml per unit.

† Calculated from the formula $\frac{\sum MC \times T}{\sum T}$.

0.3 mg per liter of air sample withdrawn from the tents. The figures in this column show that an average of about 95 per cent of the HCN had been absorbed or had escaped from the tents by the end of the fumigation period.

The mean average concentrations of HCN in the tents for the fumigation periods are shown in column 9 of table 1. These values were calculated to give due weight to the time factor by using the formula suggested by Knight (4): the mean is estimated to be equivalent to $\frac{\sum MC \times T}{\sum T}$, where MC is the mean concentration for each time interval T . The same formula was used for calculating the mean concentrations of HCN in the fumatorium, although this was not really necessary, because concentrations varied only 8.3 per cent.

For comparison, a solid-line curve representing the average concentrations of HCN in the tents at the different times of sampling is shown in figure 1 with the broken-line curve for the fumatorium. The data for the tent curve were taken from table 1. The values for the 3- and 4-minute intervals were combined and averaged as for a 3½-minute interval, and the two values (trees 1 and 5) for the 40-minute interval were averaged with those for the 45-minute interval. This method of computation and the great difference in sampling values for the first three or four intervals may make the curve of questionable worth. It does, however, illustrate clearly the difference in decreases in concentrations of HCN in the air in the tents and in the fumatorium. The final decrease in the former was approximately 95 per cent; that in the latter, only 8.3 per cent.

THE EFFECT OF PRECONDITIONING TEMPERATURES ON THE ABSORPTION OF HCN BY GREEN AND MATURE FRUITS

Quayle and Rohrbaugh (11) found no significant difference in the kill of red scale fumigated at temperatures between 50° and 90° F. They demonstrated, on the other hand, that preconditioning of red-scale-infested lemon fruits at 50° for at least 4 hours before fumigation resulted in a higher percentage of kill than preconditioning at 90°, irrespective of the temperature at which the fumigation was made. They found, also, that rooted lemon cuttings preconditioned and fumigated at 50° at a relative humidity of 70 per cent were more severely injured than similar cuttings preconditioned and fumigated at 90° at the same relative humidity.

The relation of temperature to the degree of mortality of red scale and to the injury of lemon cuttings by HCN raised a question as to the effect of temperature on the absorption of HCN by citrus tissues. Experiments were therefore planned to determine the relation between preconditioning temperatures and the amounts of HCN absorbed by citrus tissues fumigated under controlled laboratory conditions.

These experiments were performed between September 26 and November 17, 1939. Both green and mature fruits were used. Fruits were picked the night before they were to be fumigated; they were weighed, and their equatorial diameters were determined. The weights of the 17 to 20 green fruits in each sample ranged from 1,374 to 1,531 grams, and their diameters ranged from 1⅞ to 2¼ inches; the weights of the 17 mature fruits in each sample ranged from 1,521 to 1,863 grams, and their diameters ranged from 1⅞ to 2⅝ inches. Samples of green or mature fruits were preconditioned overnight (15 to 20 hours) in cabinets

maintained at temperatures of 43°, 50°, 65°, or at 80° F and at corresponding relative humidities of 78, 75, 70, and 50 per cent.

Available equipment permitted the recovery of HCN from only 2 samples at once. Under these conditions, 1 of the samples (green or mature) was preconditioned at 43° F and the other at 65° and the 2 were fumigated simultaneously. The next 2 samples were preconditioned the

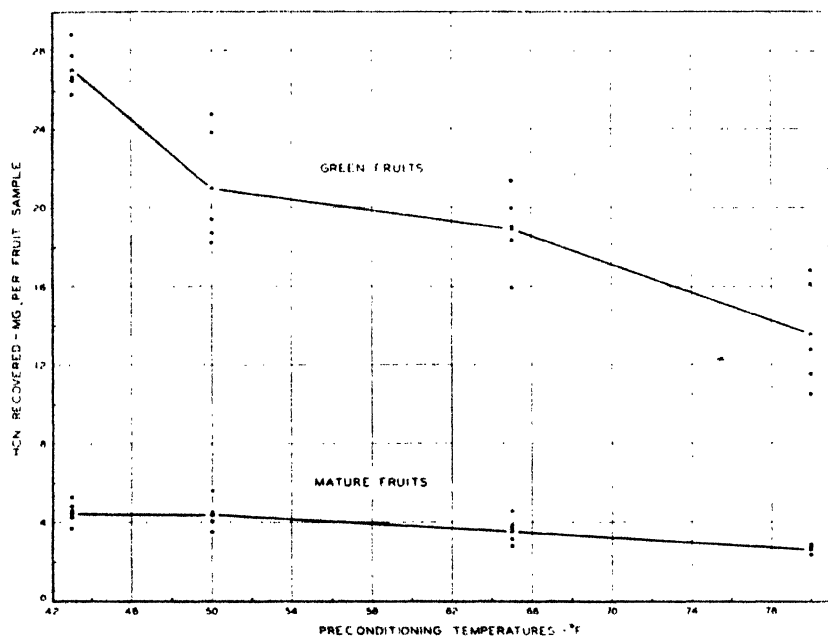


Fig. 2.—Amounts of HCN recovered from samples of green and mature Valencia-orange fruits preconditioned overnight in the laboratory at 43°, 50°, 65°, or 80° F and then fumigated in the laboratory fumatorium. The curves represent the means of the amounts of HCN recovered, while the scattered points indicate the amounts recovered from single samples. Note that the samples preconditioned at the lower temperatures absorbed more HCN than those preconditioned at the higher temperatures, and that the green fruits absorbed several times as much HCN as the mature fruits.

same day or sometimes a few days later, at 50° and 80°, respectively, before fumigation; 5 samples of green and 5 samples of mature fruits were tested at each preconditioning temperature.

After the required preconditioning period at the desired temperature, the paired fruit samples were placed in the fumatorium, fumigated, and subsequently distilled for HCN recovery. In these experiments all samples were fumigated at the same temperature, 75° F.

In order to determine the possibly injurious effects of the HCN, 6 additional fruits, which had been preconditioned at the same temperatures and relative humidities, were fumigated with each sample. After

the fumigation period, these fruits were placed in open paper bags and stored at 75° F for about 10 days to await the development of any injury that might have occurred. At the end of this storage period, the fruits were classified as good, or as slightly, moderately, or badly injured.

The relation of preconditioning temperatures to the amounts of HCN recovered from the green and mature fruits is shown in figure 2. The differences in the percentages of relative humidity that prevailed in the preconditioning cabinets did not appear to have any influence on the amount of HCN absorbed by the samples during fumigation. In addition to showing the mean values obtained at each preconditioning temperature for each kind of fruit, a point is given to represent the result of each individual test in order to show the diversity of results usually obtained when performing experiments with biological material grown under variable conditions.

The green fruits absorbed an average of 5.4 times as much HCN as the mature fruits. In general, the amount of HCN absorbed by the fruits decreased with increase in preconditioning temperature; the effect of the preconditioning temperature was not so great on mature fruits as on green fruits, however.

Although none was visible, there is a probability that some moisture condensed on the fruits that had been preconditioned at the lower temperatures (that is, at 43°, 50°, or 65° F) during the 40-minute fumigation at 75° in the fumatorium. HCN is readily soluble in water; it would therefore seem logical to conclude that the presence of the condensed moisture on the cooler fruits at least partially explains why more HCN was recovered from them than from the warmer fruits. On the other hand, the presence of a film of moisture, though not continuous, would tend to impede the entrance of HCN into the fruits; the total amount absorbed by the film and the fruit might thus be reduced (see "HCN Recovery from Mature Fruits Having Wet Surfaces," p. 389).

Perhaps it would be more logical to conclude that the cool fruits absorbed more HCN than the warm fruits because of the increased solubility of gaseous HCN at the lower temperatures. This explanation appears to agree very well with the gas law, which states that the lower the temperature, the greater the solubility of the gas. The greater viscosity of the water in or on the fruits at the lower temperatures would, of course, not interfere with the foregoing explanation. Even at the end of the 40-minute fumigation period, the fruits preconditioned at 43° F were noticeably cooler than those preconditioned at 80°. The amount of HCN recovered from the fruits preconditioned at 43° was approximately twice that recovered from the fruits preconditioned at 80° (fig. 2).

The relation between preconditioning temperatures and HCN injury to the fruits is shown in table 2. Under the conditions of these experiments, the green fruits were much more severely injured than the mature fruits. On the other hand, the quantity or degree of injury to both green and mature fruits appears to bear little or no relation to preconditioning temperature. For example, with green fruits, the total percentage injured was nearly the same for those preconditioned at 43° F as for

TABLE 2
SEVERITY AND PERCENTAGE OF HCN INJURY TO GREEN AND MATURE VALENCIA-ORANGE FRUITS PRECONDITIONED 15 TO 20 HOURS AT DIFFERENT TEMPERATURES IMMEDIATELY PRECEDING FUMIGATION

Preconditioning temperature	Percentage* of fruits having different degrees of injury			
	Slight	Moderate	Bad	Total
Green fruits				
° F	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
43	6.7	23.3	26.7	56.7
50	32.3	22.6	9.7	64.6
65	40.0	10.0	3.3	53.3
80	33.3	26.7	3.3	63.3
Mature fruits				
° F	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
43	2.8	0.0	0.0	2.8
50	0.0	0.0	0.0	0.0
65	8.3	0.0	0.0	8.3
80	0.0	0.0	0.0	0.0

* Percentage figures are based on examination of lots of 30 fruits each. These fruits were preconditioned and fumigated at the same time as those from which the data in figure 2 were obtained.

those preconditioned at 80°. The percentages of badly injured fruits which had been preconditioned at the two lower temperatures were, however, somewhat larger than for those preconditioned at the two higher temperatures. Although the injuries to these fruits were superficial and were confined to the peel (see Quayle [9], fig. 339), fruits so injured could not be shipped as first class, and a large percentage of them would have to be discarded as culls.

Why there was a noticeably higher kill of red scale on lemon fruits and greater injury to rooted lemon cuttings when fumigated after preconditioning at 50° F than when fumigated after preconditioning at 90° (11), but a lack of appreciable difference in injury to green fruits fumigated after preconditioning at different temperatures (43°, 50°, 65°, and 80°), is a question that occurs naturally at this point. The answer must await further investigation.

THE EFFECT OF OIL SPRAY ON THE ABSORPTION OF HCN BY FRUITS AND LEAVES

The results of commercial pest-control work have indicated that citrus trees are somewhat less likely to be injured by HCN fumigation if they have recently been sprayed with oil. Some experiments were therefore performed to test this observation.

Experiments with Fruits.—Fruits for a preliminary experiment were picked at intervals between February 24 and 28, 1940. All fruits were

TABLE 3
AMOUNTS OF HCN RECOVERED FROM FUMIGATED OIL-SPRAYED AND UNSPRAYED
DETACHED IMMATURE YELLOW VALENCIA-ORANGE FRUITS*

Paired samples	Fruits in each sample	Weight of fruit sample		HCN recovered per sample	
		Oil-sprayed	Unsprayed	Oil-sprayed	Unsprayed
nos.	number	grams	grams	mg	mg
573 and 574.....	12	1,586	1,609	3.3	7.9
575 and 576.....	14	1,709	1,692	3.7	7.8
577 and 578.....	14	1,720	1,698	4.5	8.3
579 and 580.....	14	1,721	1,685	2.9	5.6
581 and 582.....	14	1,725	1,600	4.3	7.4

* Fruit samples were picked between February 24 and 28, 1940, and paired. One of each of the paired samples was sprayed with a 1 per cent light-medium oil immediately after picking; the other served as an unsprayed control. Two days later both samples were fumigated in the fumatorium at the same time.

completely yellow in color but immature. Samples consisting of 12 to 14 fruits each were paired. One sample of each pair was sprayed with a 1 per cent light-medium oil by means of a precision sprayer; the other (unsprayed) sample served as a control. Two days after the fruits had been sprayed, the sprayed and unsprayed samples were fumigated in pairs in the fumatorium, the same concentration of HCN being used in each test. Table 3 shows the comparative amounts of HCN recovered from the sprayed and unsprayed samples. It is interesting to note that only about half as much HCN was recovered from the oil-sprayed as from the unsprayed fruits. Since all the fruits were yellow in color, it was to be expected that only a relatively small amount of HCN would be absorbed and recovered.

The results of this experiment were of sufficient interest to warrant the expansion of these studies to include spraying tests under field conditions. A row of Valencia-orange trees in a plot at the Citrus Experiment Station was selected. Four of the trees were sprayed very heavily with a 1½ per cent light-medium oil of the same viscosity as that used in the preceding experiment but of a different brand. Approximately 25 gallons of spray were applied to each tree. (In ordinary commercial

practice not over 20 gallons would be used on trees of this size.) Five other trees in the same row were kept for controls. Great care was exercised to prevent the spray from falling on the control trees. The spray was applied March 5, 1940, between 10:00 and 11:00 a.m., and the first samples of sprayed and unsprayed fruits were picked about 4:00 p.m. the same day. The fruits were preconditioned overnight in the laboratory at 73° F before being fumigated and distilled. Several similar sam-

TABLE 4
AMOUNTS OF HCN RECOVERED FROM IMMATURE YELLOW VALENCIA-ORANGE
FRUITS PICKED FROM OIL-SPRAYED AND UNSPRAYED TREES
AND THEN FUMIGATED*

Paired samples†	Weight of fruit sample		Total surface area of fruit sample		Date of fumigation, 1940	HCN recovered from fruit samples per 1,000 cm ² of surface	
	Oil-sprayed	Unsprayed	Oil-sprayed	Unsprayed		Oil-sprayed	Unsprayed
<i>nos.</i>	<i>grams</i>	<i>grams</i>	<i>cm²</i>	<i>cm²</i>		<i>mg</i>	<i>mg</i>
583 and 584.	1.559	1.562	1,596.3	1,586.7	March 6	3.3	3.0
585 and 586	1.557	1.563	1,586.7	1,573.3	March 6	4.4	3.9
587 and 588.	1.553	1.557	1,621.3	1,605.9	March 7	3.8	3.7
589 and 590.	1.548	1.553	1,575.7	1,606.9	March 7	3.7	3.2
591 and 592	1.545	1.555	1,567.5	1,578.1	March 8	3.1	3.3
593 and 594.	1.548	1.597	1,575.7	1,577.1	March 8	3.7	3.4
607 and 608	1.710	1.711	1,723.7	1,726.1	March 15	3.1	3.4
609 and 610.	1.655	1.697	1,706.7	1,712.8	March 15	3.2	3.2
611 and 612.	1.781	1.763	1,662.5	1,625.9	May 13	1.8	2.3

* Fruits were picked in the afternoon preceding fumigation and were preconditioned overnight in the laboratory at 73° F. The trees had been sprayed on March 5, 1940, with 1½ per cent light-medium oil.

† Samples consisted of 15 fruits each, except samples 611 and 612, which consisted of 12 fruits each.

ples were picked and treated in the same manner on the dates indicated in table 4. All fruits were immature yellow. In this experiment the HCN recoveries are expressed as milligrams per unit of fruit surface instead of for the whole sample, as in the preceding experiment.

As already pointed out (table 3), the fruits that were brought to the laboratory before being sprayed absorbed much less HCN than similar unsprayed fruits. The results in table 4 show, however, that when the fruits were sprayed in the field and then brought to the laboratory and fumigated, they absorbed as much HCN as the unsprayed control fruits. The reason for this difference is not known. It is possible that the film of 1 per cent light-medium oil applied to the fruits in the laboratory by means of the precision sprayer was thicker than that of the 1½ per cent light-medium oil applied to fruits in the field by means of the commercial power sprayer. Special care was taken to spray all outside fruits thoroughly, and only outside fruits were used in the experiments.

Apparently the length of time that the oil remained on or in the fruit did not influence the penetration of HCN, because the amount of HCN

recovered on March 6 was approximately the same as that recovered on March 15. The recoveries from the sprayed and unsprayed samples on May 13 were about equal but were smaller than the recoveries in March, probably because the fruits had matured. For comparative differences in the amounts of HCN absorbed by mature and immature fruits, see figure 2 (see, also, figs. 3, 4, 5, and 9).

The amounts of HCN recovered from the fruits in these particular experiments are below the concentrations of HCN per unit weight that would ordinarily cause injury of any great extent to the fruit at this

TABLE 5
AMOUNTS OF HCN RECOVERED FROM MATURE VALENCIA-ORANGE LEAVES
PICKED FROM OIL-SPRAYED* AND UNSPRAYED TREES
AND THEN FUMIGATED

Paired sample†	Fumigation		HCN recovered from leaves per 200-gram sample	
	Date, 1940	Hour	Oil-sprayed	Unsprayed
<i>nos.</i>			<i>mg</i>	<i>mg</i>
595 and 596	March 11	9:00 a.m.	39.7	42.4
597 and 598	March 11	1:00 p.m.	36.7	43.0
599 and 600	March 12	8:00 a.m.	44.4	41.0
601 and 602	March 12	1:00 p.m.	42.6	42.0
603 and 604	March 13	8:20 a.m.	30.0	33.1
605 and 606	March 13	1:30 p.m.	37.5	37.5

* The trees had been sprayed on March 5, 1940, with 1½ per cent light-medium oil.

† Each sample consisted of 200 grams of leaves. The samples were fumigated in pairs (sprayed and unsprayed) in the fumatorium immediately after picking.

stage of maturity. There was, accordingly, no injury to the portions of the unsprayed samples reserved for observation, but 6.25 per cent of similar portions of the oil-sprayed fruits showed slight injury. While this was not a great deal of injury, it was enough to show that the oil spray, under these experimental conditions, was injurious rather than protective in effect.

Experiments with Leaves.—The 200-gram samples of leaves used in these experiments were picked from the same oil-sprayed and unsprayed trees from which the fruits had been picked. (Counts have shown that the number of mature leaves in a 200-gram sample varies from 250 to 270.) HCN recoveries are expressed as milligrams per 200-gram sample (table 5) rather than as milligrams per unit of surface area, as was done with the fruits (table 4). The thicker the leaf, the greater is the weight per unit area; on this basis the samples used might have had different surface areas. It is very probable, however, that the surface areas of the samples were similar, because the samples consisted of a composite of leaves picked at random from all the sprayed trees and from all the unsprayed trees, respectively.

In this particular experiment the oil spray did not have a retarding effect on the penetration of HCN into the leaves. Several years ago Quayle (8) observed that sprays made from "heavy" oils protected orange trees from HCN injury even when fumigated with unusually high dosages of HCN (220 per cent schedule). As a result of further investigation on this problem, Quayle and Ebeling (10) stated that:

Hydrocyanic acid is not absorbed by the oil, consequently there may be less absorption by the tree where the surface is covered with oil; if so, a higher concentration of HCN could be used in the air surrounding the insect, without injury to the tree. Some tests have shown that an oil-sprayed tree is less likely to be injured by fumigation than a tree under the same conditions which has not been sprayed (Quayle, 1922) [(7)]. Other comparative tests have shown that there is little or no increased protection from oil spray coverage.

The spray oils in use at the present time are lighter than those formerly used, but the opinion still prevails among growers and commercial operators that oil sprays tend to protect citrus trees against HCN fumigation injury. It is generally admitted, however, that there have been many cases in which the oil spray had no apparent protective effect.

THE EFFECT OF MOISTURE CONTENT OF TISSUES ON THE ABSORPTION OF HCN

It is important to determine the relation between the moisture content of citrus leaves and fruits and the amount of HCN which they absorb during fumigation, for this relation is not only fundamental to the understanding of the physiological effects of HCN in the tissues but also important from a practical viewpoint. Many growers and fumigators are of the opinion that during the summer months, other factors being equal, considerably more injury will result to citrus trees if they are fumigated when the soil is wet than when it is comparatively dry. During the winter months, however, there appears to be little or no relation between injury to the tissues and soil moisture, for the trees can be successfully fumigated after a rain just as soon as the ground will permit the fumigators to operate. The two following experiments were performed to determine any relation that might exist between the moisture content of leaves and fruits and the amount of HCN they would absorb when fumigated under laboratory conditions.

HCN Recovery from Fumigated Fresh and Partially Wilted Mature Leaves.—The purpose of this experiment was the determination of the comparative amounts of HCN that may be absorbed by fresh and by partially wilted mature Valencia-orange leaves when fumigated in the fumatorium. About 525 grams of mature leaves were picked at random from 6 to 8 trees, brought to the laboratory, and thoroughly mixed. One

100-gram sample of these leaves was used for determining total moisture content; 2 samples of 200 grams each were fumigated in the fumatorium after the moisture content of 1 sample had been reduced.

The moisture content of the leaves in the partially wilted sample was reduced the desired amount (usually 15 per cent of the fresh weight) by spreading the leaves in a $\frac{1}{4}$ -inch-mesh wire tray, 20 inches long, 13 inches wide, and 2 inches deep. The tray was supported in the upper end of a carton about 3 feet high and open at top and bottom. The carton was placed over a hot plate, with a 3-inch space between the bottom of the

TABLE 6
AMOUNTS OF HCN RECOVERED FROM FUMIGATED FRESH AND
WILTED MATURE VALENCIA-ORANGE LEAVES*

Paired samples	Moisture in leaves (fresh-weight basis)		HCN recovered from leaves per 200-gram sample	
	Fresh	Wilted	Fresh	Wilted
<i>nos.</i>	<i>per cent</i>	<i>per cent</i>	<i>mg</i>	<i>mg</i>
613 and 614.....	57.0	47.0	45.7	41.6
615 and 616.....	57.2	42.2	43.0	41.7
617 and 618.....	57.5	42.5	41.6	42.1
619 and 620.....	56.6	41.6	44.2	45.1
621 and 622.....	57.9	42.9	41.3	41.1
623 and 624.....	55.8	40.8	46.3	44.6

* Tests were made May 14 to 24, 1940. About 525 grams of mature leaves were picked at random from 6 to 8 trees for each test. One 200-gram sample of these leaves was kept in an airtight container while another 200-gram sample was being wilted (about 20 minutes). A third sample of 100 grams was used for moisture determination. The fresh and wilted samples were fumigated simultaneously in the fumatorium.

carton and the floor to insure good ventilation. By weighing the leaves at intervals, the desired loss in moisture content could be determined. Fresh leaves were kept in an airtight container during this process (about 20 minutes). Paired samples of fresh and wilted leaves were then fumigated at the same time.

Table 6 shows that under these experimental conditions there was no significant difference between the amounts of HCN absorbed by fresh and by wilted leaves. The results of this experiment indicate that if there is any great difference in injuries when fumigations are conducted under dry and under wet conditions, the injury to the tissues is not wholly dependent upon the amount of HCN absorbed. These fresh and wilted leaves had been detached and were fumigated in the laboratory, however; results may therefore not be indicative of what would have happened had fresh and wilted leaves been fumigated in the field while attached to the trees.

HCN Recovery from Fumigated Turgid and Nonturgid Green Fruits.
—The tests on turgid and nonturgid fruits were similar to those on fresh

and wilted leaves. For each test, 2 samples of fruit were collected in the late afternoon. The fruits of 1 sample were cut with stems about 12 to 18 inches long; those of the other sample were clipped without stems. The stems of fruits of the first sample were immediately submerged in water and recut to a length of about 6 or 8 inches, then transferred to Erlenmeyer flasks containing tap water. Upon being brought to the laboratory, the sample with the stems was placed in a glass-walled humidity cabinet; the one without stems was put in an open paper bag and set in the same room outside the cabinet. The temperatures and humidities to which the different samples were exposed between the time of collection and fumigation are shown in table 7.

The paired samples were fumigated the following day. Just before fumigation the stems were removed from the turgid sample, and the fruits in both samples were weighed and measured, so that the comparative total surface areas of the 2 samples could be determined. The fruits with stems had become very turgid; the others had become slightly wilted.

The results recorded in table 7 show the comparative amounts of HCN absorbed by, and recovered from, the turgid and nonturgid samples of fruit. No significant difference is noticeable between the 2 samples of each pair. There was, however, a marked difference in the amounts of HCN recovered from the different samples within each of the two groups—turgid and nonturgid. The mean concentrations of HCN in the fumatorium during each fumigation period were much the same, yet the amounts of HCN recovered gradually increased at each successive fumigation. The prefumigation and HCN-recovery treatments were the same for all samples; therefore no explanation can be given for these results, unless one may say that during this period the fruits were undergoing some physical or chemical change which made them more susceptible to HCN absorption. The results of these fruit tests (table 7) are similar to those for the leaves (table 6) in that there was no appreciable difference in the amounts of HCN absorbed by turgid and nonturgid tissues.

After each fumigation, aliquot samples of turgid and nonturgid fruits were placed in paper bags and stored in a room at 75° F for about 10 days. They were then examined for the presence of HCN injury and were classified as uninjured or as slightly, moderately, or badly injured. The comparative effects of the HCN on the turgid and nonturgid fruit samples, expressed in mean percentages, are shown in table 8. Although there were no significant differences in the amounts of HCN recovered from the samples, 84 per cent of the turgid fruits were injured, as compared with only 29 per cent of the nonturgid fruits.

TABLE 7
AMOUNTS OF HCN RECOVERED FROM TURGID AND NONTURGID GREEN VALENCIA-
ORANGE FRUITS FUMIGATED IN PAIRS IN THE FUMATORIUM*

Paired sample†	Preliminary storage conditions for fruits				Total weight of fruits		Total surface area of fruits		Mean concentration of HCN in fumatorium per liter of space	HCN recovered from fruit per 1,000 cm² of surface	
	Relative humidity		Temperature		Turgid	Nonturgid	Turgid	Nonturgid		Turgid	Nonturgid
	per cent	Nonturgid	° F	° F							
					grams	grams	cm²	cm²	mg	mg	
noe.	90	54	75	75	1.778	1.568	2.421	2.241	1.4	3.8	3.7
743 and 744.....	84	54	74	74	1.742	1.511	2.376	2.215	1.4	4.3	4.9
745 and 746.....	88	50	75	74	1.624	1.501	2.279	2.175	1.3	5.2	5.6
747 and 748.....	89	49	73	70	1.632	1.431	2.188	2.075	1.3	6.2	6.6
749 and 750.....	90	49	71	71	1.555	1.424	2.251	2.083	1.4	8.1	7.1
751 and 752.....											

* Tests were made August 21 to September 6, 1940.

† Samples 743 to 748 consisted of 35 fruits each; samples 749 to 752 consisted of 30 fruits each. Fruits of 1 sample of each pair were made turgid by placing with stems in water in a humid chamber for 15 to 20 hours; fruits of the other sample of each pair were made nonturgid by storing in open paper bags for the same period of time at the temperatures and relative humidities indicated. Paired samples were fumigated in the fumatorium simultaneously.

HCN Recovery from Mature Fruits Having Wet Surfaces.—It is well known that HCN has a great affinity for water, and that the two are mutually miscible in all proportions. Since this is true, it was decided to determine the comparative amounts of HCN that could be recovered from fumigated fruits having wet and dry surfaces.

TABLE 8
INJURY TO TURGID AND NONTURGID GREEN VALENCIA-ORANGE FRUITS,
CAUSED BY FUMIGATION WITH HCN*

Fruit samples	Fruits uninjured	Fruits injured			
		Slightly	Moderately	Badly	Total
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Turgid	15.8	23.7	0.0	60.5	84.2
Nonturgid	71.4	16.7	4.8	7.1	28.6

* The values given are the mean percentages for 5 samples each of turgid and nonturgid fruits.

TABLE 9
COMPARATIVE AMOUNTS OF HCN RECOVERED FROM WATER-SPRAYED AND UNSPRAYED
MATURE VALENCIA-ORANGE FRUITS FUMIGATED IN THE FUMATORIUM*

Paired samples†	Weight of fruits		Total surface area of fruits		HCN recovered from fruits per 1,000 cm ²	
	Water-sprayed	Unsprayed	Water-sprayed	Unsprayed	Water-sprayed	Unsprayed
<i>nos.</i>	<i>grams</i>	<i>grams</i>	<i>cm²</i>	<i>cm²</i>	<i>mg</i>	<i>mg</i>
625 and 626	1.663	1.653	1.681	1.678	3.9	5.3
627 and 628	1.682	1.693	1.710	1.720	3.8	4.9
629 and 630	1.673	1.692	1.727	1.733	2.9	4.7
631 and 632	1.683	1.669	1.700	1.714	2.1	3.8
633 and 634	1.670	1.753	1.728	1.737	2.1	3.1
641 and 642	1.839	1.835	1.816	1.792	1.9	3.4

* Tests were made between May 27 and June 18, 1940.

† Each sample consisted of 15 fruits selected at random from 6 to 8 trees. As soon as the fruits of each pair of samples had been picked, weighed, and measured, those of 1 sample were sprayed with water; the others were left unsprayed. Both samples were fumigated at the same time.

Paired samples of mature Valencia-orange fruits were picked and brought to the laboratory for weighing and for determining of total surface areas. Fruits of 1 sample were then sprayed with water; those of the other sample were left unsprayed. A small amount of a wetting agent was added to the spray water, so that the surface of the sprayed fruits would be covered with a film of water. The fumigation was done immediately after the spraying was completed, and the sprayed and unsprayed samples were both fumigated at the same time. When the samples were taken from the fumatorium, the sprayed fruits were still moist. These fruits were washed with distilled water before they were cut, and this water was then added to that in the distillation flask.

The results of this experiment (table 9) show that less HCN was recovered from the water-sprayed fruits than from the unsprayed fruits. The presence of the film of water on the surface of the water-sprayed fruits appears to be the most plausible explanation for these results. The thickness of the water film was, of course, not known; but the thicker the film, the greater should be the amount of HCN absorbed by it, and the smaller the amount passing into the fruit during the 40-minute fumigation period. The results indicate that because of the water-film barrier, a comparatively small amount of HCN entered the sprayed fruits. The thickness of the water film and the partial pressure of gaseous HCN in the fumatorium therefore largely determined the amounts of HCN recovered from the water-sprayed fruits and their water films.

During the warm months of the year, fumigators cease fumigation when visible moisture begins to collect on the leaves and fruit, for fumigation is then likely to result in injury to the tissues. The results of this experiment substantiate previous evidence to the effect that injury under such conditions is caused, not by the presence of the moisture on the fruits and foliage, but by unusual gas pressure due to the decrease in permeability of the tent wall (9). It seems probable that the condensed moisture on the leaves and fruits would not be sufficient to retard materially the entrance of HCN into the tissues, especially in the presence of unusually high gas pressure. Injury under these conditions would probably be comparable to the injury resulting to the fruits that were made very turgid by placing them with their stems in water in a humid chamber overnight before fumigation (table 7).

More fundamental work should be done on this problem before definite conclusions are drawn, however. For example, the partial pressure of HCN under a damp fumigation tent at the end of a 45-minute fumigation period may not be relatively high, because the excessive moisture on the tree may absorb the HCN as rapidly as it would have passed out through the walls of a comparatively dry tent (9). On the other hand, it seems probable that the initial pressure of gaseous HCN in a moist tent would be unusually high for at least the first few minutes. A condition of this kind, even if of short duration, might mean the difference between injury and noninjury to the tree.

THE RECOVERY OF HCN FROM FUMIGATED GREEN FRUITS FROM COASTAL AND INLAND AREAS

When fumigated with HCN, citrus trees are more subject to injury during the fall months (September, October, and November) than at any other time of the year. Practical experience in southern California has shown, also, that when fumigated during this susceptible period,

under comparable conditions, citrus trees in the coastal areas are usually more easily injured than those in the inland areas.

This situation led to the formulation of plans for determining the comparative amounts of HCN absorbed by green Valencia-orange fruits from coastal and from inland areas when fumigated in the laboratory under controlled conditions. Furthermore, it was planned to correlate the amount of HCN absorbed, with the severity of injury to the tissues.

Samples were taken daily for four periods of 4 days each between December 5, 1939, and January 27, 1940. On each day 1 sample was picked in the coastal area and 1 in the inland area and brought to the laboratory for measuring and weighing. The fruits were preconditioned at 65° F for 15 to 20 hours before fumigation. Paired samples of fruits from each area were fumigated at the same time, and HCN recoveries were made in the usual manner. Samples collected in December, 1939, contained 23 fruits each, of which 17 were used for HCN determinations; but in January, 1940, the fruits being larger, each sample contained only 20 fruits, of which 14 were used for HCN determinations. The 6 extra fruits in each sample were stored at 70° after fumigation and were later observed for injury.

The fruits from the coastal area were picked from one grove located at Santa Ana and from three other groves within 3 miles of, but in different directions from, Santa Ana. All fruit samples from the inland area came from two plots at the University of California Citrus Experiment Station.

These experiments were repeated and refined during the fall and winter of 1940-41. The three groves selected in the coastal area were located near those of the previous year; the three groves in the inland area were within 3 to 8 miles of Riverside. In each grove, plots containing 26 trees were selected, and all samples were taken from these plots at 2- to 3-week intervals, from October 8, 1940, to February 11, 1941. Methods of sampling, preconditioning, and fumigating were the same as those of the previous year, except that additional fruits were picked at each sampling period for maturity determinations (expressed by the percentage of soluble solids and acids in the juice and by the ratios of these two). The purpose of the maturity determinations was to investigate any possible relation between the maturity of the fruits and the amounts of HCN they would absorb. Each sample for HCN determination contained 15 fruits, and all fruits in a given pair of samples (inland and coastal) were similar in size.

The results of the 1939-40 determinations are shown in figure 3. Each value is the average of 2 samples and represents milligrams of HCN recovered per unit of fruit surface. In general, the coastal fruits ab-

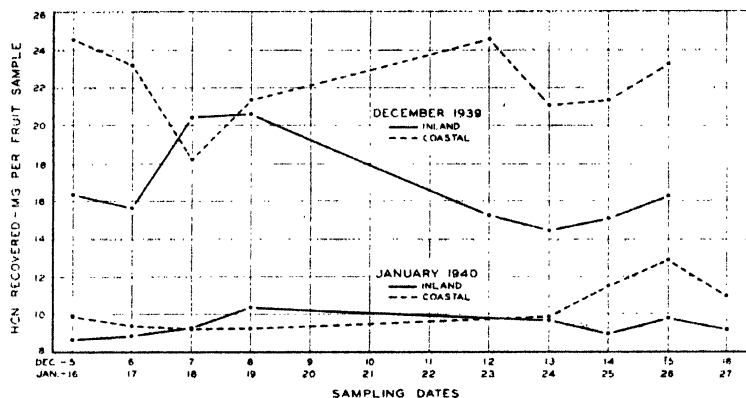


Fig. 3.—Amounts of HCN recovered from Valencia-orange fruits brought from groves in the inland and coastal areas and fumigated in the laboratory fumatorium in 1939-40. Each point on the curves represents the average of the amounts recovered from 2 samples of 15 fruits each. Compare these curves with those in figures 4 and 5, which show the results of a similar experiment in 1940-41.

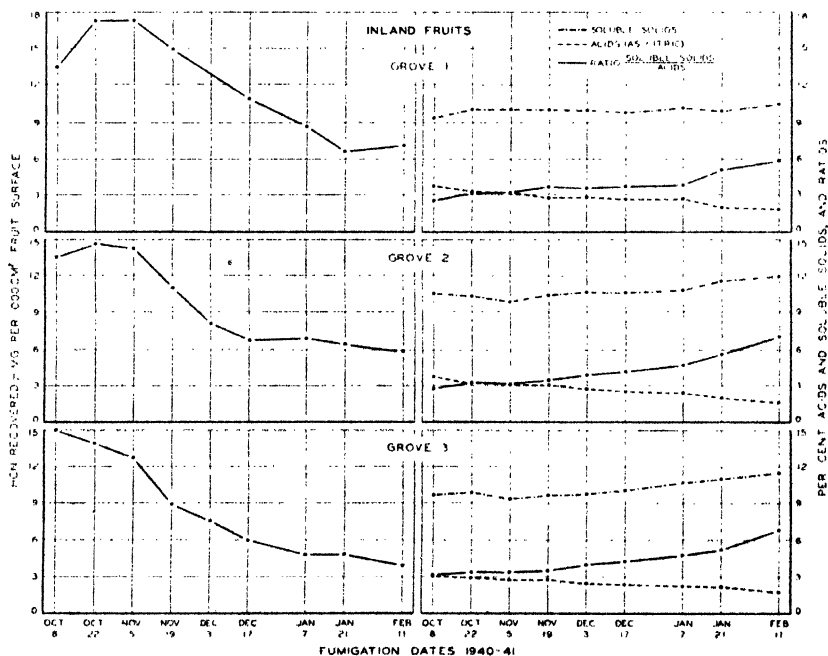


Fig. 4.—The amounts of HCN recovered from Valencia-orange fruits brought from groves in the inland area and fumigated in the laboratory fumatorium in 1940-41. Note the decreasing amounts of HCN recovered as the fruits became more mature. The increasing maturity of the fruits is shown by the curves for acids, soluble solids, and ratios. Compare these values for fruit samples from the inland area with those for the samples from the coastal area, shown in figure 5. Each point on the curves represents the average of the amounts recovered from 2 samples.

sorbed more HCN than the inland fruits. On only two dates, one in December and one in January, was there plainly less absorption of HCN by coastal fruits than by inland fruits; but there were two dates in January on which the absorptions for the fruits from the two areas were practically the same. The crossing of the curves and the individual differences shown in amounts of absorption within a given month are probably due to the condition of the fruits from the different groves at

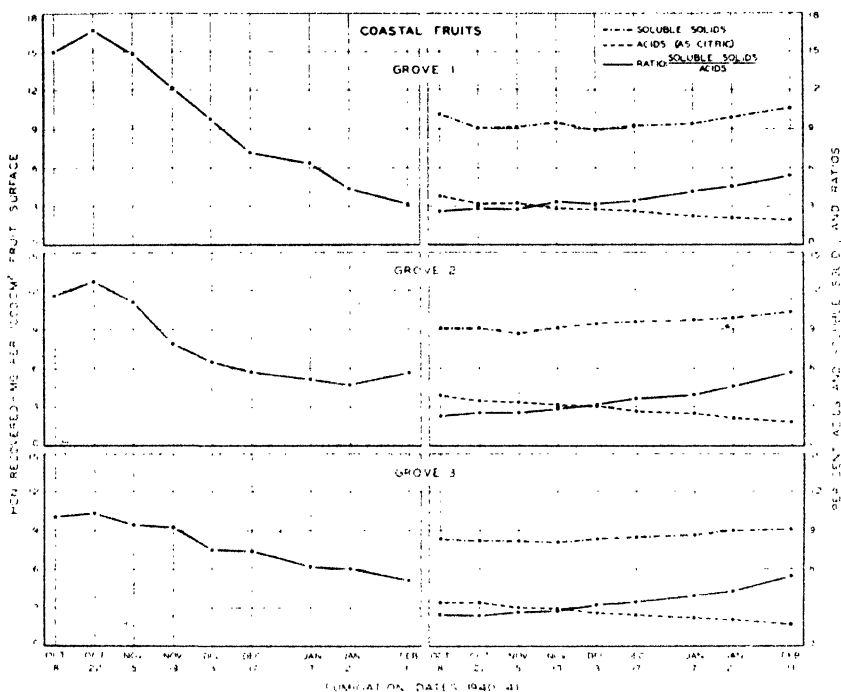


Fig. 5.—The amounts of HCN recovered from Valencia-orange fruits brought from groves in the coastal area and fumigated in the laboratory fumatorium in 1940-41. Note the decreasing amounts of HCN recovered as the fruits became more mature. The increasing maturity of the fruits is shown by the curves for acids, soluble solids, and ratios. Compare these values for fruit samples from the coastal area with those for the samples from the inland area, shown in figure 4. Each point on the curves represents the average of the amounts recovered from 2 samples.

the time they were fumigated. The absorption of less HCN by January fruits than by December fruits verifies the general observation that the more mature the fruits, the less HCN they will absorb.

The results of the 1940-41 determinations for inland and for coastal fruits are shown in figures 4 and 5, respectively. These figures show recoveries of HCN and determinations of fruit maturity for each of the three groves in the two areas separately. After the second determination

(October 22), as the fruits became more mature, there was a gradual diminution in the amounts of HCN absorbed. There was, on the other hand, a gradual upward trend in percentages of soluble solids and in ratios of soluble solids to acids, with a decrease in titratable acidity. The inland samples, as a whole, absorbed an average of 15 per cent more HCN than the coastal samples (just the reverse of what occurred in 1939-40). In only 6 of the 54 paired determinations was more HCN absorbed by the coastal than by the inland samples. The explanation for the reversal of results is not known.

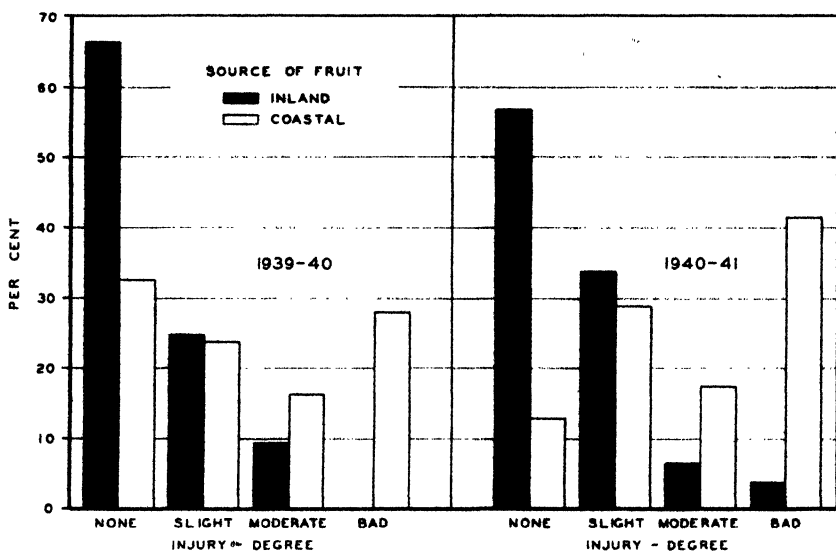


Fig. 6.—Comparative percentages of uninjured and HCN-injured fruits from inland and coastal areas for the seasons of 1939-40 and 1940-41 (see figs. 3, 4, and 5). None of the inland fruits were badly injured in 1939-40.

Since all determinations to date have shown that the more mature the fruit in any particular grove becomes, the less HCN it will absorb, the results of the 1939-40 determinations were tentatively explained on the basis that the inland fruits were more mature than those from the coastal area and therefore absorbed less HCN. Such an explanation will not hold for the 1940-41 results, however. Figures 4 and 5 show that at the time determinations were made, inland fruits were, again, more mature than coastal fruits (as shown by ratios of soluble solids to acids) but absorbed more rather than less HCN. Perhaps such reversals of results should be expected, however, with materials that are subject to a wide variety of biological and climatic factors.

Despite the fact that the inland fruits absorbed less HCN than the coastal fruits in 1939-40 and more HCN than the coastal fruits in

1940-41, the comparative amounts of HCN injury on the fumigated inland and coastal fruits, as shown in figure 6, were consistent. Injury, in both years, was much more evident on the coastal than on the inland fruits: For example, in 1939-40, 68 per cent of the coastal fruits but only 34 per cent of the inland fruits were injured; in 1940-41 the figures were 87 and 43 per cent, respectively. The results of 1940-41 are of special interest because the inland fruits absorbed more HCN than year than the coastal fruits, yet were much less severely injured.

THE FIXATION OF HCN BY FUMIGATED GREEN FRUITS

Experiments were planned to determine at what rate HCN would be liberated from fumigated fruits when a definite volume of air was drawn over them. It was important to know if the fumigated fruits continued to liberate HCN with an increase in the time of aspiration, or if the release of the HCN occurred within a definite time during aspiration.

Four experiments were made between September 19 and October 2, 1940. Eight samples, consisting of 25 green fruits each, were used in each experiment and were fumigated simultaneously. Fruits were sorted to have as nearly as possible the same weight and total surface area. The weight of the samples ranged from 1,349 to 1,528 grams—a difference of 179 grams; and the total surface areas ranged from 1,836.4 to 1,950.7 sq. cm—a difference of 114.3 sq. cm. Since the experiments required 32 samples (800 fruits), the total variation in the weight and surface area of the individual samples was relatively small and sufficiently close for comparative purposes.

In each experiment, before fumigation, all samples were preconditioned overnight at 71° F and 70 per cent relative humidity. After the fumigation period, the HCN absorption was determined immediately on 2 of the 8 samples, to serve as checks. Each of the other 6 samples was placed in a Pyrex-glass desiccator (6-liter capacity). All 6 desiccators were connected to individual absorption bottles containing 100 ml of *N* NaOH solution; these, in turn, were connected to a suction pump through a Greiner rotameter gauge for measuring the total volume of air passing through the desiccators and, subsequently, through the alkaline solutions in the bottles. (Preliminary experiments showed that all HCN liberated by the fruit in such tests would be caught by the NaOH solution in the absorption bottles.) Incidentally, the lower end of the inlet tube extended almost to the bottom of each desiccator, so that the air would pass over the fruit on its way to the outlet in the top.

The volume of air flowing over each sample of fruit was 33.3 liters per hour. This means that, after correction for fruit volume, there was

a complete change of air in each 6-liter desiccator approximately every 8 minutes. At this rate of change of air, any HCN liberated by the fruit should have been carried over and absorbed by the NaOH in the absorption bottles.

At the end of chosen periods of aspiration (table 10), 2 desiccators and their absorption bottles were disconnected, and the rate of aspiration for the remaining samples was then readjusted so that it would be unchanged from the original rate. HCN determinations (in milligrams per unit of fruit surface) were at once made on the 2 fruit samples. The

TABLE 10
AMOUNTS OF HCN RELEASED BY CONTROL AND ASPIRATED SAMPLES OF
FUMIGATED GREEN VALENCIA-ORANGE FRUITS*

Experiment no.	Amounts of HCN released					
	Controls	Samples aspirated for:†				
		4 hours	24 hours	28 hours	33 hours	48 hours
	mg	mg	mg	mg	mg	mg
1.....	13.5	2.6	2.7	...	...	1.4
2.....	8.6	1.7	1.8	...	2.1	...
3.....	12.2	1.8	1.8	1.8	...	...
4.....	12.1	2.6	2.6	...	...	3.3

* Experiments were performed between September 19 and October 2, 1940.

† Each value for a given experiment represents the average amount of HCN released by 2 control samples or by 2 aspirated samples, and is based on the amount of HCN released per 1,000 cm² of fruit surface. No sample was aspirated more than once. For the average amounts of HCN remaining in the aspirated samples at the end of the aspiration periods, plus the amounts that these samples released while being aspirated, see figure 7.

NaOH solution in each disconnected absorption bottle was diluted to 1 liter in a volumetric flask. Aliquot portions of 150 ml were taken from these flasks for the titration of HCN, which, in turn, was used to calculate the total HCN in the absorption liquids.

Each value in table 10 represents the average amount of HCN given off by 2 separate samples of fruit. No sample was aspirated more than once. Values in this table show that, under the conditions of these experiments, the amounts of HCN liberated from the fruits and caught in the absorption bottles were comparatively small, and that the HCN was practically all liberated during the first 4 hours of aspiration.

The average total amounts of HCN recovered from the 2 samples of fruit and their absorption liquids in each experiment are shown in figure 7. The curves in this figure indicate that the total amounts of HCN recovered decreased with each increase in the length of time of aspiration, and that the amounts recovered after the first 4 hours were comparatively small. The amounts of HCN in the absorption liquids plus the amounts that remained in the fruits at the end of any given aspira-

tion period were small in comparison with the total amounts of HCN absorbed by the fruits during the 40-minute fumigation period (shown at the zero aspiration time in fig. 7). The results show very plainly that under these conditions a comparatively large proportion of the HCN absorbed had been fixed or so changed that it could not be recovered by the usual methods. The curves in the figure show that as much as 85

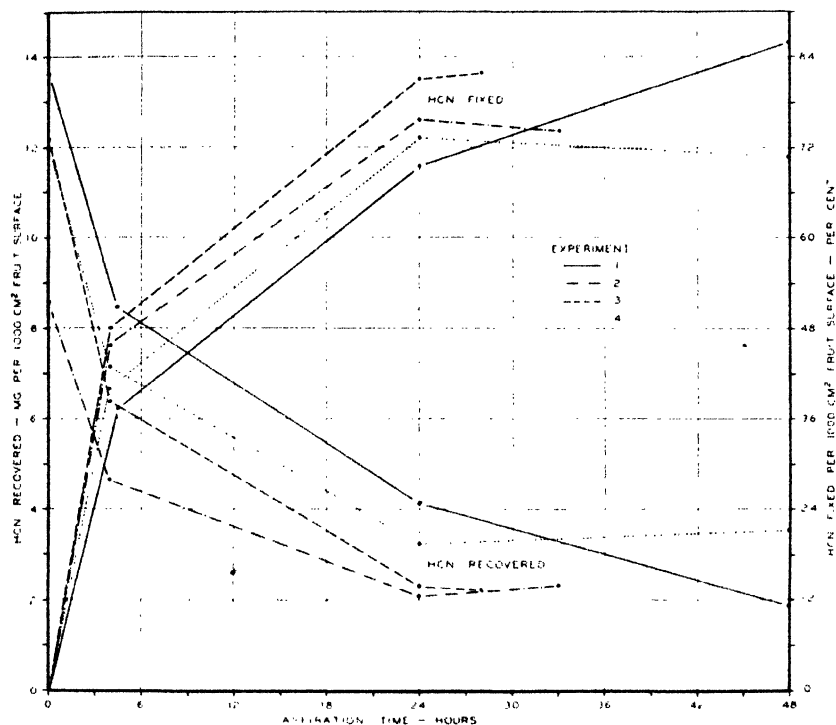


Fig. 7.—Amounts of HCN recovered from samples of green Valencia-orange fruits immediately after fumigation in the laboratory fumatorium and from similar samples and their respective absorption liquids after different intervals of aspiration. The figure also shows the percentages of HCN fixed in fruit samples by the end of each aspiration period. Each point on the curves represents the average of 2 samples.

per cent of the absorbed HCN had been fixed or changed in those samples that were not tested until the end of the 48-hour aspiration period.

The fixation of HCN by green fruits was further investigated by determining the HCN in fruit samples immediately after fumigation (to serve as controls) and by placing other samples, which had been fumigated at the same time, in 5-liter Pyrex flasks. The flasks were sealed with rubber stoppers covered with tin foil. In each stopper there was an inlet tube that extended to the bottom of the flask and an outlet tube

that terminated at the bottom of the stopper; both tubes had glass stop-cocks. Each sample consisted of 25 green fruits of approximately the same age and size as those used in the preceding experiments. The samples were sealed in the flasks for 48 hours. After this period the flasks were connected by means of glass tubing to absorption bottles containing 100 ml of *N* NaOH. Air was drawn through the flasks and bottles at the rate of 60 liters per hour for 2 hours. The HCN was then determined in the fruit samples and in the absorption liquids. The contents of each absorption bottle were diluted to 1 liter in a volumetric flask, and 150-ml aliquots were used for HCN determinations. These experiments were performed during the latter part of September, 1940.

TABLE 11
FIXATION OF HCN BY FUMIGATED GREEN VALENCIA-ORANGE FRUITS
SEALED IN GLASS CONTAINERS*

Experiment no.	HCN recovered from:†			HCN fixed by sealed fruits
	Control fruits	Absorption liquid	Sealed fruits	
	mg	mg	mg	mg
1.....	16.5	0.0	0.0	16.5
2.....	23.4	0.0	3.0	20.4
3.....	22.6	0.0	2.1	20.5

* Sealed for 48 hours.

† Each value represents the total amount recovered from a single fruit sample or from the corresponding absorption liquid.

The amounts of HCN recovered from the control fruits, the absorption liquids, and from the sealed fruits, and the amounts of HCN fixed by the sealed fruits are shown in table 11. No HCN was found in the absorption liquid in any of the aspiration bottles. Any HCN that had escaped from the fruits into the flasks had been reabsorbed during the 48-hour period. No HCN could be recovered from 1 of the fruit samples that had been sealed in a flask for 48 hours, and only 3.0 and 2.1 mg, respectively, could be recovered from the other 2 sealed samples.

The results of these experiments confirm those of the aspiration experiments, showing that green Valencia-orange fruits readily fix HCN to the extent that it can no longer be recovered as HCN by the steam-distillation method.

THE RECOVERY OF HCN FROM LEAVES AND FRUITS OF FUMIGATED TREES

To state even approximately how much HCN a citrus tree will absorb during a fumigation period is difficult, owing to many factors, including the physiological condition of the tree at the time of fumigation and

those factors already described as affecting the concentration of HCN under the tent (see "HCN Concentrations in Tents," p. 375). Nevertheless, important information has been obtained on this problem by conducting experiments to determine the amounts of HCN that citrus leaves and fruits will absorb during the 45-minute fumigation period and how long they will retain the HCN when the trees are fumigated under different conditions in the field. Such information is of vital importance in studying the causes of HCN injury to the tissues, and no information of this kind has been available up to the time of these experiments.

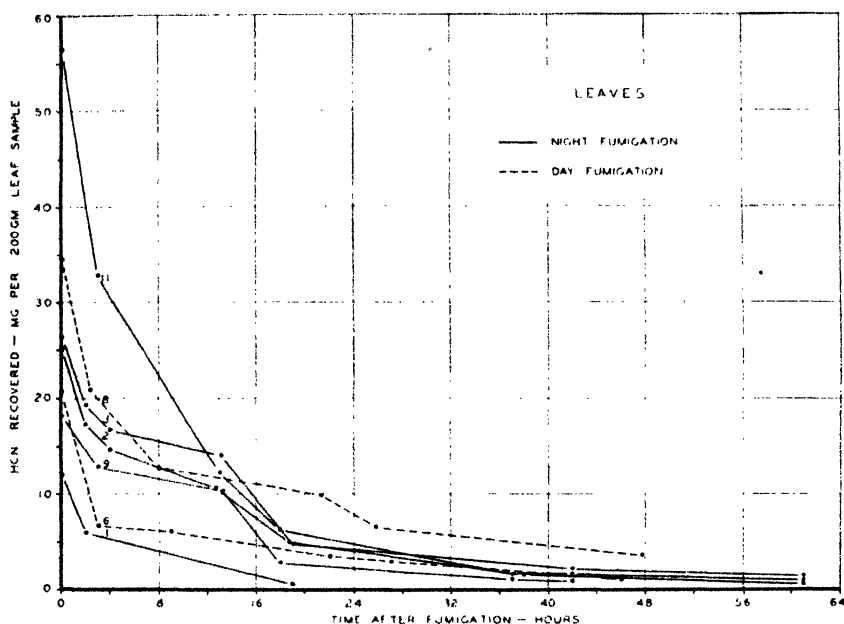


Fig. 8.—Amounts of HCN recovered from 200-gram samples of mature Valencia-orange leaves from trees fumigated at night and from trees fumigated during the day. Note differences in initial recoveries and in lengths of time the leaves retained the HCN. The numerals on the curves designate tree numbers. Each point on the curves represents the average of the amounts recovered from 2 samples.

The experiments on the fumigation of Valencia-orange trees under field conditions were conducted between September 20 and November 14, 1939, and between July 23 and August 15, 1940. Equipment was not available to make recoveries of HCN on samples of leaves and fruits picked from the same tree at the same time. This meant that at a given fumigation, either leaves or fruits had to be chosen for the determination of the HCN.

The first samples of leaves and fruits were taken from the trees just as soon as the fumigation tents had been removed. Other samples were

taken at intervals to determine the length of time the HCN would remain in the tissues. The samplings were continued until the tissues yielded only a few milligrams of HCN or none at all.

Figures 8 and 9 show the relation between the time intervals after fumigation and the amounts of HCN recovered from the leaves and fruits. There was wide variation in the amounts of HCN recovered from the samples of mature leaves picked immediately after the tents were removed. The differences in the slopes of the curves also show that the

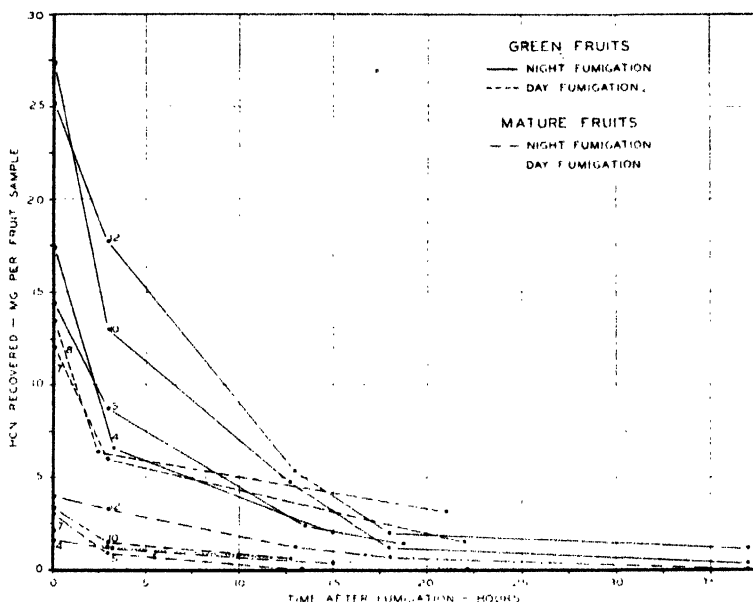


Fig. 9.—Amounts of HCN recovered from samples of green and of mature Valencia-orange fruits from trees fumigated at night and from trees fumigated during the day. Note the differences not only in initial recoveries and in lengths of time the HCN was retained, but also in amounts of HCN recovered from green and from mature fruits. Curve 12 for mature fruits is extended to the 37-hour point, but the fruits contained no HCN at this time and only 0.71 mg at the time of the 18-hour test. The numerals on the curves designate tree numbers.

rates of loss of HCN from the individual trees were vastly different. The results of these experiments and of those of other investigators (6, 9, 11) show the effect on HCN absorption of the physical factors which influence the concentration of HCN in the gaseous phase under the tent.

HCN Recovery from Leaves.—It is obvious that any reduction in the amount of HCN under the tent during a fumigation period would be reflected in the amount recovered from the leaves. This is well illustrated by results obtained from trees 1, 2, and 3 (fig. 8): The first 200-gram

samples of leaves picked from tree 1 immediately after fumigation gave an average yield of 12.2 mg HCN, while those picked 19 hours later yielded only 0.6 mg. In contrast, the leaf samples from trees 2 and 3 gave initial yields of 25.4 and 26.6 mg HCN, respectively, and similar samples picked from the same trees 61 hours later yielded 0.7 and 1.6 mg, respectively. The leaf samples from tree 1 did not yield so much HCN initially as those from trees 2 and 3, nor did they retain it so long.

Tree 1 was fumigated at 6:52 p.m., September 20, 1939, at a temperature of 80° F and a relative humidity of 50 per cent. The mean concentration of HCN under the tent during the fumigation period was 0.9 mg per liter of space (table 1, p. 377). The air was very still during the fumigation period, but a strong, dry north wind arose 20 minutes after the removal of the tent from the tree. The low relative humidity permitted excessive gas leakage through the tent wall during the fumigation period, and the rapid air movement soon after the tent was removed quickly dissipated the HCN liberated from the tissues after the removal of the tent. This type of environmental condition during the fumigation of citrus trees under field conditions is conducive to low absorption of HCN, and, conversely, to low recoveries from the fumigated leaves.

Tree 2 was fumigated at 6:50 p.m., September 27, and tree 3 at 6:35 p.m., October 4, 1939. The temperatures at the time of fumigation of trees 2 and 3 were 65° and 64° F, and the relative humidities were 80 and 87 per cent, respectively. The mean concentrations of HCN under the tents during the fumigation periods for trees 2 and 3 were, respectively, 1.4 and 1.6 mg per liter of space under the tent (table 1).

Mention should be made also of the fact that by the time the third samples of leaves were collected from tree 2 (4 hours after fumigation), and the second samples from tree 3 (2 hours after fumigation), the leaves had become damp with condensed moisture. This condition no doubt influenced the length of time that these leaves retained the HCN.

Trees 9 and 11 were fumigated at the same hour in the evening as trees 2 and 3 and at approximately the same temperatures and relative humidities, on July 31 and August 12, 1940, respectively. The mean concentrations of HCN in the tents over trees 9 and 11 were both 0.9 mg per liter of space (table 1). In spite of the fact that the mean concentrations of HCN in the tents over these trees was the same, the leaf samples from tree 11 yielded much more HCN and retained it much longer than those from tree 9 (see fig. 8).

Sufficient data on which to base an explanation for these results are not available. Tree 9 was fumigated just before an irrigation, and tree 11 soon after an irrigation. The leaves on tree 9 did not appear to wilt during the day, but the leaves on an adjoining grapefruit tree of about

the same size and in the same row wilted visibly during the warm part of the day. Tree 11 was fumigated after the irrigation water had had time to penetrate but while the soil was still wet on the surface. The leaves on tree 11 had become damp by the time the second samples were taken at 10:30 p.m. Whether these conditions were responsible for the fact that the leaves from tree 9 absorbed much less HCN than those from tree 11 cannot be stated. In this connection, however, it may be pointed out that the moisture content of fresh and partially wilted leaves and of turgid and nonturgid fruits fumigated in the laboratory did not appear to govern the amount of HCN that they absorbed (see tables 6 and 7); and that during the warm months of the year, a grove or a portion of a grove fumigated while the soil is wet is much more likely to be injured than one fumigated while the soil is comparatively dry.

The information on the fumigation of these trees is given in detail to show that although they were all fumigated with the same schedule of HCN (20 ml per unit), the mean concentration of HCN per liter under the tent was not the same during each fumigation period. These differences, together with the comparative differences in physiological, climatic, and other factors operating at the time of fumigation, were sufficient to cause variation in the total absorption and length of retention of HCN by the tissues.

Another interesting relation is observed when recoveries of HCN from leaves of trees fumigated during the day are compared with those from leaves of trees fumigated at night. Trees 6 and 8 (fig. 8) were fumigated at 9:45 a.m., July 23, and at 10:30 a.m., July 29, 1940, at temperatures of 97° and 75° F and at relative humidities of 31 and 58 per cent, respectively. The mean concentrations of HCN in the tents over trees 6 and 8 during the fumigation period were 1.4 and 1.8 mg per liter of space, respectively (table 1). As shown in figure 8, the leaves from tree 6 absorbed and retained less HCN than those from tree 8. The amounts of HCN yielded by the leaves from the trees fumigated during the day were, in general, comparable to those from trees fumigated at night.

The comparative results of the night and day fumigations were of special interest because the trees fumigated at night suffered very little or no injury, while those fumigated during the day were severely injured, especially on those portions of the trees that received direct sunlight. The direct sunlight probably made the cutinized surfaces of the leaves more permeable to HCN, although this effect was not registered in the HCN yields of these leaves, as compared with the yields of those fumigated at night. It is possible that the leaves fumigated during the day absorbed more HCN than those fumigated at night, but that photochemical action, either on the HCN or on the tissues, caused them to fix

excessive amounts of the absorbed HCN, which could not be recovered. However this may be, it was very evident that photochemical or other changes had made the tissues very susceptible to HCN injury.

The results of this experiment are of interest because they at least indicate that the stomata are not an important factor in governing the rate of entrance of HCN into citrus leaves. These results with citrus do not confirm the findings of Clayton (3), who worked with tomatoes and *Tradescantia zebrina* (*Zebrina pendula*) and concluded that the amount of HCN absorbed by the leaves depended upon the width of the stomatal openings. They do, however, substantiate the results of Stone (12) and Moore (5), who concluded that other attributes of the tissues were more important than the stomata in regulating the absorption of HCN. The excessive injury to the leaves fumigated during the day may have been due to the much greater physiological activity of the tissues during the day than at night, although this explanation does not appear to harmonize with the fact that rooted lemon cuttings were more severely injured at low than at high temperatures (11).

HCN Recovery from Fruits.—Other trees were fumigated for the purpose of studying the absorption and retention of HCN by fruits. Trees 4 and 5 were fumigated at night on October 18 and November 11, 1939; trees 7 and 8, during the day of July 26 and 29, 1940; and trees 10 and 12, at night on August 5 and 15, 1940, respectively. Paired samples of green and mature fruits were tested from all the trees, except tree 8, from which only green fruits were used. The range in concentrations of HCN in the tents during the fumigation periods and the range in temperatures and relative humidities were similar to those for the preceding experiment, in which leaves instead of fruits were tested. Green and mature fruits for each pair of samples were selected for uniformity in size and similarity in weight.

Experimental results are illustrated in figure 9, in which the total milligrams of HCN recovered from the fruit samples are plotted against the time intervals after fumigation. Results are expressed in total milligrams of HCN recovered from each sample rather than per unit of surface area, because the method for determining the surface area of the fruits had not been worked out at the time the first tests in this series were made.

The lack of uniformity in the amounts of HCN recovered from the fruits in this experiment (fig. 9) is similar to that for the leaves (fig. 8). Again the effects of environmental and other factors are evident. The main point of interest in this experiment, however, is the comparatively large difference between the amounts of HCN recovered from the samples of green and of mature fruits. An average of 6.3 times as much HCN

was recovered from the green fruits as from the mature fruits. These results compare very favorably with those of the preconditioning experiment (fig. 2), in which 5.4 times as much HCN was recovered from the green fruits as from the mature fruits. With reference to the comparative amounts of HCN absorbed by green and by mature fruits, the same relation held, whether the fruits were fumigated during the day or at night. Traces of HCN could be recovered from some of the leaf samples 61 hours after fumigation, but the maximum period for recovery of HCN from the fruit samples was 37 hours after fumigation.

The results of these fruit experiments again emphasize the importance of the physiological condition of the tissues in governing the amount of HCN that they will absorb and the extent to which they will be injured, if at all.

DISCUSSION

The results previously reported in this field of investigation (2) and those reported in this paper are the only ones which give quantitative information on the amounts of HCN absorbed by citrus tissues during the fumigation period and on the length of time that recoverable HCN remains in the tissues after the fumigation period. The discussion of these experimental results is concerned largely with the factors which may have influenced absorption and retention of the HCN. No attempt has been made to bring into the discussion all the results obtained by other workers, which may have a bearing on the data described in this paper. The work of Woglum (13) is mentioned here because it probably has a more extensive and direct application than any of the other published data on the effects of HCN on citrus tissues.

Woglum did not make quantitative determinations on the absorption and retention of HCN by the plant tissues, but he did make extensive observations on the presence or absence of injury to citrus trees subjected to different temperatures, moistures, amounts of light, and so forth, before, during, and after fumigation. As a result of his experiments he concluded that "it is necessary to consider the prefumigation and postfumigation environments of fumigated plants as well as that during the actual treatment."

In the present experiments, all paired fruit samples contained equal numbers of fruits, so chosen that they were, as nearly as possible, of the same age and size. The weights of the 2 samples of each pair were therefore approximately the same. This procedure minimized sample differences and placed the HCN recoveries on a reasonably comparable basis. In the major portion of this work, where fruits were concerned, the HCN recoveries were placed on a still more comparable basis by measuring the total surface area of the fruits in each sample and ex-

pressing the amounts of HCN recovered as milligrams per unit of fruit surface. The results obtained by this method show that the recoveries of HCN per 1,000 sq. cm of fruit surface ranged from approximately 5.5 mg for young fruits (about 4.5 cm in diameter) to approximately 1.0 mg for fruits that were fully mature (6 to 8 cm in diameter), a wide and interesting difference.

The HCN recoveries from mature leaves are expressed as total milligrams per 200-gram sample. The total surface areas of the fumigated samples of leaves were not determined, but since these experiments were completed, the surface areas of several 200-gram samples have been measured with a photoelectric area determinator made by the American Instrument Company. These determinations show that the average 200-gram sample of mature leaves has a total surface area (both sides of leaves) of 13,500 sq. cm. This figure is only approximate; the difference between the total surface areas of 2 samples may be as great as 10 per cent. On the basis of a total surface area of 13,500 sq. cm per 200 grams of mature leaves, the average recovery of HCN from the samples of "unsprayed" and "fresh" leaves (tables 5 and 6) was 3.1 mg. per 1,000 sq. cm. The average recovery per unit area from samples of mature fruits was much less than this, and that from immature fruits much greater.

The results of earlier studies by other research workers on the fumigation of plants (including citrus) with HCN, before efficient methods for the recovery and determination of minute amounts of HCN were available, indicated that the degree of injury to HCN-fumigated tissues was proportional to the amount of HCN absorbed. There is considerable evidence, however, from the experimental results presented in this paper, that this is not the case when citrus tissues are concerned.

It is true that green fruits in the present studies were found to absorb more HCN than mature fruits; that experimental results already published (2) showed that immature leaves absorbed more HCN than mature leaves; and that, in both cases, the tissues that absorbed the most HCN were those most severely injured. It seems probable, however, that these results were not entirely due to the comparative amounts of HCN absorbed but to some other factor or factors. For example, there was practically no difference in the amounts of HCN recovered from day- or night-fumigated leaves, from day- or night-fumigated fruits, or from turgid or nonturgid fruits; and in 1940-41 the coastal fruits absorbed less HCN than the inland fruits; yet the first-mentioned leaves or fruits of all four of these experiments were more severely injured than the others. Other experiments have shown that green fruits from a given grove may absorb less HCN but be more severely injured than similar fruits from a different grove, which absorbed more HCN.

Such results as these strongly indicate that the extent of injury to fumigated citrus tissues is governed principally by such factors as sunlight and by the physiological condition of the tissues rather than by the amount of HCN absorbed. The importance of the physiological condition of the tissues was indicated by the earlier work of Woglum (13).

In the course of these studies it has been of special interest to find that as soon as the color of the fruit changes from green to yellow or orange, there is usually a noticeable decrease in the amount of HCN absorbed during fumigation either in the laboratory or in the field (figs. 2 and 9). The amount of HCN absorbed is apparently not entirely controlled by the presence of chlorophyll or by the conditions which accompany photosynthetic activity, however, because some green fruits will absorb more than others of a similar age and size from a different grove or even from the same grove. The physiological conditions which influence the absorption of HCN by citrus tissues remain to be determined by future studies.

The curves in figures 8 and 9 show that, after fumigation at night under field conditions, recoverable HCN may remain in mature fruits for 20 to 25 hours, in green fruits for 35 to 40 hours, and in mature leaves for at least 60 hours. Without further data, it is difficult to suggest an explanation for these differences. Adsorption, tissue composition and structure, climatic conditions, and the fixation of HCN by the tissues are all important factors in governing the length of time that recoverable HCN will remain in the tissues.

The experiments on the fixation of HCN (see "The Fixation of HCN by Fumigated Green Fruits," p. 395) showed that fumigated green fruits sealed in flasks had fixed almost all of the sorbed HCN by the end of 48 hours. Possibly the mature leaves, which retained recoverable HCN for the greatest length of time, were less active physiologically than the green fruits and thus fixed less HCN. On this basis, however, the mature fruits, which were presumably less active physiologically than the green fruits, should have retained their HCN longer than the green fruits; this they did not do.

In earlier studies (2), it was shown that during the fumigation period, gaseous HCN penetrated not only to the inner surface of the peel but also into the pulp of the fruit. Although the depth of penetration into the pulp was not determined, it was several times the thickness of a mature leaf. Because of the comparative thinness of the leaves, it would seem that they should have lost their HCN sooner than the fruits, which was not the case. The tissues of the leaf are more compact than those of the fruit peel, and those of the green fruit are more compact than those of the mature fruit. Therefore, the most plausible explanation for the

difference in lengths of time that the HCN remained in the leaves and in green and mature fruits appears to be that the more compact the tissues, the longer they will retain HCN.

SUMMARY

Some of the factors influencing the absorption and retention of HCN by citrus tissues have been determined by conducting fumigation experiments in a gastight metal fumatorium in the laboratory and in regulation canvas tents in the field.

The concentrations of HCN remained nearly constant in the fumatorium but, as might be expected, varied greatly in the tents during the fumigation periods (fig. 1 and table 1).

Considerably more HCN was absorbed by fruits preconditioned overnight at 43° F before fumigation than by those preconditioned at 80°, and green fruits absorbed an average of 5.4 times as much HCN as mature fruits (fig. 2).

Under laboratory conditions the absorption of HCN by fruits was retarded by the application of oil spray, but both fruits and leaves sprayed under field conditions absorbed as much HCN as unsprayed fruits and leaves (tables 3, 4, and 5). In the laboratory none of the fruits were injured by the HCN; in the field none of the unsprayed, but about 6 per cent of the oil-sprayed fruits were injured.

Less HCN was absorbed by leaves and fruits on trees that had not been recently irrigated than by those on trees that had been recently irrigated (fig. 8, curves 9 and 11), but there was no appreciable difference in the amounts of HCN absorbed by turgid and nonturgid leaves and fruits fumigated in the laboratory (tables 6 and 7). The turgid fruits were more severely injured than the nonturgid fruits. Fruits sprayed with water and a spreader and fumigated at once, absorbed less HCN than similar fruits whose surfaces were dry (table 8).

In 1939-40, green fruits from inland areas absorbed less HCN than green fruits from coastal areas (fig. 3); but in the similar experiment in 1940-41, the inland fruits absorbed more HCN than the coastal fruits (figs. 4 and 5). The coastal fruits were much more severely injured than the inland fruits both years (fig. 6).

Green fruits fixed or chemically changed absorbed HCN so that it could not be recovered and determined by the usual methods (fig. 7).

Leaves and fruits of trees fumigated during the day absorbed approximately the same amounts of HCN as those fumigated at night, but were much more severely injured. In these experiments recoverable HCN was retained by mature leaves for at least 60 hours, by green fruits 35 to 40 hours, and by mature fruits 20 to 25 hours (figs. 8 and 9). An

average of 6.3 times as much HCN was recovered from the green fruits as from the mature fruits.

The stomata are apparently not important in governing the rate of entrance of HCN into citrus leaves and fruits.

The physiological condition of the tissues rather than environmental influences or the amount of HCN absorbed seems to determine whether they will or will not be injured by HCN after fumigation at night; injury after day fumigation appears to result from the effects of sunlight, which raises the temperature and influences the physiological condition of the tissues.

The results of laboratory fumigations may, but do not always, indicate the results that will be obtained when the fumigations are made under field conditions.

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INFECTION OF PERENNIAL DELPHINIUMS BY CALIFORNIA-ASTER-YELLOWS VIRUS¹

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INTRODUCTION

SEVERAL OBSCURE diseases attack garden varieties of perennial delphiniums (hybrids and horticultural varieties of several species of *Delphinium*) and cause losses to seed companies, nurserymen, and growers. One of these diseases is particularly troublesome, sometimes causing delphiniums grown from seed to fail totally the second year. Some of the choicest seeds, requiring hand-pollination and bagging, are grown in California; and often these hybrid seeds, also selected for mildew resistance, are lost owing to this disease. Because the symptoms resemble those of California aster yellows on other host plants, an investigation was undertaken to determine whether this disease is caused by the virus of California aster yellows.

In the course of the work on this disease, several other delphinium virus diseases and troubles resembling viroses were investigated. The reports of these investigations have been divided into six papers. The present paper is confined to the work with California aster yellows on perennial delphiniums. Experiments with two other naturally occurring viroses of perennial delphiniums are reported in the other papers of this issue (18, 22).³ The attempts to infect perennial delphiniums experimentally with other viruses are reported in a fourth paper (20). Two leaf variegations of perennial delphiniums resembling viroses but not infectious were encountered; these are reported in a fifth paper (19). Several of the virus diseases attacking perennial delphiniums affect also annual delphiniums, or larkspur (*Delphinium Ajacis*); the experiments with this host plant are published in a sixth paper (21).

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³ Italic figures in parentheses refer to "Literature Cited" at the end of this paper.

California aster yellows is a serious disease of aster and celery, and affects also lettuce (13), carrots, parsley, and parsnip (14), and many ornamentals (23). Except in a preliminary note (25) based on this investigation, however, it has not previously been reported on delphinium. Nevertheless, the symptoms described by several investigators in other states indicate that they may have been dealing with this disease.

In 1927 Linford (33, 34) reported 50 per cent of yellows (cause undetermined) on tall perennial delphinium at Logan, Utah; he evidently suspected the disease to be aster yellows but stated that delphiniums were not known to be susceptible to that disease, and conducted no tests.

In 1933 Hungerford (35) reported a new virus disease on delphinium at Moscow and Boise Valley, Idaho, and suggested "witches'-broom" as a common name.

Orton (10) reported a new virus disease of delphiniums in the Northwest called "greens," which stunts the plants and makes them produce nothing but dwarfed green flowers.

Heald and Burnett (6) described a virus disease of perennial delphinium in the State of Washington and applied the name "stunt" to the disease.

A more complete discussion of the same delphinium disease in that state was published by Burnett (2), again under the designation "stunt." Several references on the distribution of "stunt" (virus) of delphinium in the states of Washington and New York have appeared in the *Plant Disease Reporter* (36, 37, 38).

In the present investigation, the symptoms of the disease on naturally infected delphiniums were compared with those on delphiniums experimentally infected with California aster yellows. Field investigations were undertaken to determine the most important vectors of the virus of delphiniums. Attempts were made to recover the virus from naturally infected delphiniums by the mountain leafhopper, *Thamnotettix montanus* Van D.; the geminate leafhopper, *T. geminatus* Van D.; the short-winged aster leafhopper, *Macrostes divinus* (Uhl.) (= *Cicadula divisa*), and the long-winged aster leafhopper, a physiological race or variety of the same species (17); and to transfer it to healthy aster and celery plants. Attempts were made to infect healthy delphiniums grown from seeds with the virus obtained from diseased aster and celery plants by the four vectors and to recover the virus from the infected delphiniums and transfer it back to healthy aster and celery plants by previously noninfective leafhoppers. The delphinium varieties and hybrids experimentally infected, the incubation period of the disease in delphiniums, and the weed reservoirs of the virus in and near delphinium fields were also investigated.

METHODS

Rhubarb (*Rheum Rhaponticum*) is immune to California aster yellows and was found to be a favorable breeding plant of the geminate leafhopper. Adults collected on delphiniums in the field were confined in cages enclosing rhubarb plants in which they oviposited. The adults were removed from the cages before the nymphs hatched from the eggs. The males reared during the nymphal stages on rhubarb plants, as well as adults of the later generations, were frequently transferred to celery plants, but caused no infection. Males were used instead of females, to avoid egg deposition.

The production of noninfective short-winged aster leafhoppers (reared on mildew-resistant Sacramento barley immune to aster yellows), mountain leafhoppers, and geminate leafhoppers (the last two reared on healthy celery) have been described in previous papers (14, 16). The long-winged aster leafhopper also remained noninfective when reared on Sacramento barley.

SYMPTOMATOLOGY

The description of the symptoms of aster yellows pertaining to the abnormal development of the flower is in general terminology, since no anatomical comparison has been made of the normal and abnormal flower structures.

One of the most conspicuous symptoms of aster yellows on naturally infected delphiniums, when roguing of diseased plants is not practiced, is the dwarfing of some of the plants. A general yellowing of the foliage occurred on the stunted plants. It was not uncommon to find a dense cluster of yellow shoots about 6 inches high which never developed spikes. A closer examination of one of these shoots revealed numerous lateral or axillary shoots (plate 1, A) bearing abnormal leaves—instead of 3 lobes or divisions, 2 lobes may be dwarfed, or 1 or 2 lobes may be absent (plate 1, C), or the blades may be linear or even seem to be reduced to the midvein with threadlike petioles (plate 1, A).

Frequently many slender shoots from 6 to 12 inches or more in height grow from the crown. The petioles are elongated with chlorotic leaves, which may be cupped inward (plate 2, C, D). These slender shoots may remain dwarfed until the blossoming period or they may develop slender spikes. It was not unusual to find delphinium plants 3 to 5 feet high with spikes bearing abnormal flowers and with slender, chlorotic shoots, which never developed spikes, at the base of the plant.

Other striking symptoms of aster yellows on naturally and experimentally infected delphiniums were several abnormalities in the de-

velopment of the flowers. Green flower buds (plate 3, *A*) expanded into enlarged green leafy sepals and dwarfed petals (plate 3, *B*; plate 4, *A*, *B*). The most remarkable peculiarity was the appearance in the normal position of the carpels of structures resembling leaves with green blades and petioles; the petals were dwarfed and surrounded by enlarged green sepals (plate 3, *C*; plate 4, *D*, *F*). Frequently the sepals, petals, carpels, and stamens were replaced by green leafy structures (plate 3, *D*), and sometimes enormous clusters of these abnormal floral parts developed at the apical region of the spike (plate 2, *B*).

Phyllody, or the transformation of stamens, petals, carpels, or all of the floral parts into leafy structures, is frequently caused by parasites, but other disturbances, such as general effects of soil excesses or over-nutrition, may produce similar effects (5). Phyllody and virescense, or greening of the flowers, are common symptoms of aster yellows among ornamentals, economic plants, and weeds. In all probability these symptoms described by plant teratologists on many plants are caused by this virus.

A sectorial infection was observed on some delphinium plants in which normal-colored flowers and abnormal flowers with green, leafy sepals and petals occurred on opposite sides of the same spike (plate 2, *A*). Sometimes abnormal flowers with green floral parts were found on the spikes of one or more stalks and apparently normal flowers on the spikes of the remaining stalks. A cluster of apparently normal flowers was present on the apical region and often near the basal region of spikes, with the intermediate or basal region of the spikes bearing filamentous structures (plate 5, *A*, *B*). Dwarfed flowers with elongated pedicels were found on some spikes (plate 5, *C*). A closer examination of the dwarfed flowers showed median-green areas on the petals (plate 5, *G-J*).

Spikes were observed in the field with clusters of abnormal flowers surrounded by dwarfed single-lobed bracts (plate 5 *D*) or with 3-lobed, dwarfed leaves arranged to form a rosette, with central, dwarfed, floral parts (plate 5, *E*, *F*; plate 4, *C*). A considerable amount of variation occurred in the formation of the rosette; often it was composed of 3-lobed leaves, dwarfed sepals, and petals (plate 5, *K*) or cupped leaves and sepals, and dwarfed petals (plate 5, *L*). An examination of the central floral parts of some rosettes under the binocular microscope showed peculiar structures which resembled dwarfed flower buds (plate 4, *E*), sometimes one bud attached by a stalk to another bud (plate 4, *G*), or the carpels replaced by a stem bearing variously modified appendages.

Frequently a proliferation of the apical end of the spike occurred and resulted in variable types of malformations, which confused some grow-

ers, who doubted that all of the extremely varied symptoms were produced by a single virus. Sometimes a dense cluster of leaves enclosed abnormal, green flowers (plate 6, *A*); or a cluster of leafy structures replacing normal sepals, petals, carpels, and stamens, with lower normal-shaped leaves (plate 6, *B*); or linear, leafy structures representing abnormal floral parts with lower single-lobed leaves (plate 6, *C*); or a bunched, tangled mass of flower parts (plate 6, *D*); or an apical, central cluster of abnormal flowers with filamentous flower organs and lateral branches with dwarfed, apical leaves surrounding abnormal green flowers (plate 7, *A*). The abnormal, green flowers with filamentous sepals and petals were not always found in clusters. They often were arranged and spaced on the spikes like those of healthy plants (plate 7, *B*). Sometimes a cluster of green flowers with long pedicels appeared on the apical end of the spike, with lateral branches surrounded by linear leaves (plate 7, *C*). Numerous slender branches of the spike with dwarfed, abnormal, green flowers suggested a witches'-broom appearance (plate 7, *D*).

Delphiniums naturally infected with aster yellows sometimes show necrotic symptoms on the stems, petioles, and blades, but these symptoms are probably caused by secondary bacterial infections and not directly by the aster-yellows virus. Sometimes such dark-brown or black lesions or necrotic streaks of variable size, shape, diameter, and length occurred on the stems (plate 8, *A*, *D*, *E*). Sometimes black blotches girdled the stem (plate 8, *G*) and caused death of the shoots (plate 8, *H*). Sometimes cracks in the stems followed the necrotic streaks (plate 8, *F*). The necrotic streaks appeared on the petioles (plate 8, *A*), sometimes at or near their attachment (plate 8, *C*). Black necrotic specks resembling bacterial leaf spot (plate 8, *C*) occurred on the blades; these often coalesced to form large irregular areas (plate 8, *B*), and sometimes spread over and killed the entire leaf (plate 8, *H*). These symptoms were common on delphiniums grown under natural conditions during the second or later years, but have not been observed on seedlings in seedbeds or cold frames or on experimentally infected plants grown in the greenhouse.

Stalks of delphiniums infected with aster yellows may fall over between the rows before or during the blossoming period. Many of the stalks may be severed but others still adhere to the roots, the leaves often wilting (plate 6, *E*). The stalks frequently showed necrotic streaks and often black lesions. In the spring of 1939 few stalks had dropped up to April 18, but by May 3 it was difficult to walk between the rows owing to the number of stalks which had dropped.

Similar necrotic symptoms on the blades, petioles, and stems, and the lodging or falling over of the shoots have been described by Heald and

Burnett (6), Burnett (2), and Mulford (9) with delphinium "stunt" of Washington, but again these symptoms are probably produced by secondary bacterial invaders and not directly by the aster-yellow virus.

Delphinium seedlings experimentally infected with aster yellows developed greatly elongated, vertical or upright, frequently curved, yellow petioles (plate 1, *B*) with dwarfed, chlorotic leafblades often cupped inward. Naturally infected delphinium seedlings showed similar symptoms except that the petioles were shorter (plate 1, *D*). The greatly elongated petioles developed only when kept in cages in the greenhouse where the light intensity is lower. Delphiniums experimentally infected before or after the spikes began to grow during the second season, developed chlorotic, cupped leaves, often with curved petioles (plate 2, *D*).

The effect of the disease on the flowers was noted on experimentally infected varieties or hybrids. Seedlings infected during the spring often produced a bloom late the first year in the glasshouse, and all infected plants produced abnormal green flowers on the dwarfed spikes. Some of the infected seedlings died before spikes began to grow. Delphiniums infected during the second year before the spikes appeared developed abnormal, green flowers with enlarged, cupped sepals, and sometimes leafy structures from the carpels (plate 3, *C*; plate 4, *F*). Delphiniums infected after the spikes appeared the second year sometimes failed to produce green flowers with abnormal floral parts but developed a dense cluster of short, yellow shoots from the crown after blossoming.

INSECT VECTORS

Three species of leafhoppers have previously been reported (16) to transmit the California-aster-yellows virus to aster and celery plants. The short-winged aster leafhopper transmitted the virus with greater efficiency than the mountain leafhopper and the geminate leafhopper. The transmission of the virus by the mountain leafhopper to celery averaged 26.1 and to aster 2.9 per cent, and by the geminate leafhopper to celery 13.7 per cent; but this species failed to transmit the virus to asters. In experiments not previously reported, 120 healthy asters were inoculated, using lots of 3 to 30 male or female geminate leafhoppers to each aster, but not a single case of aster yellows developed, even though a total of 697 adults were used, all of which had completed the nymphal stages on diseased celery plants. During 1941, 25 lots of 50 male geminate leafhoppers reared on diseased celery were transferred to healthy celery plants; and after celery yellows developed, each lot was transferred to 2 successive healthy asters. Typical symptoms of aster yellows appeared on 4 of 50 asters inoculated.

Garden varieties of perennial delphiniums are unfavorable food plants of short-winged and long-winged aster leafhoppers. A high mortality occurred on delphiniums; some of the leafhoppers died within 4 to 6 hours and most of them within 24 hours.

Perennial delphiniums are, however, favorable food and breeding plants of the mountain and geminate leafhoppers under natural conditions. Large populations of nymphs and adults of the mountain leafhopper were taken on perennial delphiniums near Mt. Eden and Capitola during the autumn. Nymphs and adults of the geminate leafhopper were abundant on perennial delphiniums near Salinas. The life histories of both species of leafhopper were completed on delphiniums in the greenhouse.

Vectors Collected on Naturally Infected Delphiniums.—Thirteen lots of 20 male or female mountain leafhoppers collected on delphinium naturally infected with aster yellows near Mt. Eden on October 2, 1937, were transferred to healthy Blackmore and Langdon Giant or Summer Cloud delphiniums, one lot to a plant; 11 of 13 plants, or 84.6 per cent, developed typical symptoms of the disease.

A similar test was made with the geminate leafhopper collected on diseased delphiniums near Salinas on September 15, 1937; 12 of 13 plants, or 92.3 per cent, developed symptoms of aster yellows. Four lots of 20 males, which transmitted the virus to the first set of delphiniums, were transferred to a second set of plants, and all of these became diseased. One lot of 20 males failed to transmit the virus to either of 2 successive delphiniums.

Recovery of Virus from Naturally Infected Delphiniums.—A comparison was made of the ability of the four vectors to recover the virus from naturally infected perennial delphiniums obtained from Mt. Eden and to transfer it to healthy aster or celery plants. The mountain leafhopper and short-winged and long-winged aster leafhoppers were tested by feeding each vector on separate infected delphiniums. In another test, all three of these and also the geminate leafhopper were fed on the same infected plant. Previously noninfective males were used in all tests. The number of delphiniums used in each test, the number of insects on each plant, and the length of time the insects were fed on infected delphiniums, and on healthy aster or celery plants when symptoms failed to develop are indicated in table 1. In spite of the short exposure of delphiniums to the aster leafhopper (6 to 18 hours) high mortality reduced the average number of short-winged aster leafhoppers transferred to aster to 16 per plant and that of the long-winged to 17 per plant even at room temperature. Table 1 shows the recovery and transfer of the virus by the four vectors.

Repeated attempts have been made during the past ten years to recover the virus from naturally infected delphiniums by means of the short-winged aster leafhopper, but all efforts failed owing to the fact that this insect rarely picks up the virus in short feeding periods from diseased delphiniums.

TABLE 1
RECOVERY OF CALIFORNIA-ASTER-YELLOWS VIRUS FROM NATURALLY INFECTED
DELPHINIUMS BY FOUR VECTORS

Vector	Length of time fed		Delphiniums naturally infected	Insects on each delphinium	Plants inoculated		Plants infected		Percentage infected
	On delphinium	On aster or celery			Aster	Celery	Aster	Celery	
	days	days	number	number	number	number	number	number	per cent
Mountain leafhopper (<i>Thamnotettix montanus</i>).....	7	32	9	20	0	9	..	0	0.0
Short-winged aster leafhopper (<i>Macrostelus divius</i>).....	¼-¾	39	25	25-30	25	0	1	..	4.0
Long-winged aster leafhopper (<i>M. divius</i>).....	¼-¾	36	19	25-30	19	0	4	..	21.0
Mountain leafhopper (<i>T. montanus</i>)*.....	7	32	24	20	0	24	..	5	20.8
Geminate leafhopper (<i>T. geminatus</i>)*.....	6	34		20	0	24	..	1	4.2
Short-winged aster leafhopper (<i>M. divius</i>)*.....	¼-¾	39		25-30	24	0	0	..	0.0
Long-winged aster leafhopper (<i>M. divius</i>)*.....	¼-¾	36		25-30	24	0	4	..	16.7
All vectors.....			77	.....	92	57	9	6	10.1

* All four vectors were fed in succession on an infected plant and then transferred separately to healthy aster or celery plants.

EXPERIMENTAL INFECTION

Delphinium Varieties and Hybrids.—The following delphinium varieties and hybrids⁴ grown from seeds were experimentally infected with the aster-yellows virus by means of four vectors. No attempt has been

⁴ Of these delphiniums grown from seeds, nos. 1, 2, and 3 are from Ferry-Morse Seed Co., San Francisco; no. 4 from Germain Seed and Plant Co., Los Angeles; nos. 5, 6, 7, 8, 9, 10, and 11 from Hallawell Seed Co., San Francisco; no. 12 from Aggeler & Musser Seed Co., Los Angeles; and nos. 13 and 14 from Henry A. Dreer, Philadelphia, Pa.

made to determine the species in most cases, since the origin of many garden varieties, hybrids, and races of delphiniums is unknown.

1. Blackmore and Langdon Giants
2. Dwarfed Chinese Blue Butterfly
3. Tall hybrid Bellamosum
4. Pacific Giant strain
5. Cambridge Blue No. 2828
6. Chinese Azure Blue No. 2821
7. Chinese Dark Blue No. 2822
8. Chinese Blue Butterfly No. 2823
9. Cliveden Beauty No. 2837
10. *Delphinium grandiflorum* var. *album*
11. Improved Wrexham or Hollyhock strain
12. A & M Sunbeam hybrids
13. Dreer's De Luxe hybrids No. 2160
14. White Elatum (Summer Cloud) No. 2149

Incubation Period of the Disease.—The incubation period of the disease was determined in delphinium seedlings and during the second year's growth before and after spikes developed, the later tests being conducted to ascertain the effect of the disease on the flower parts.

Four delphinium varieties or hybrids grown from seeds were inoculated during June. The 12 to 15 plants of each kind were divided among the four vectors, each plant being inoculated singly by one lot of 20 males of one vector. Short-winged and long-winged aster leafhoppers all died within 1 day. The cages containing the mountain or geminate leafhoppers were removed at the end of 1 day from the seedlings and replaced with empty cages. In this experiment all delphinium seedlings inoculated by any of the four vectors developed symptoms of the disease. The length of time from the day of inoculation until the petioles became chlorotic, elongated, vertical, with dwarfed, chlorotic, frequently cupped leaves, was considered as the incubation period of the disease. The results obtained are indicated in table 2. The check, or control, plants of all delphinium varieties and hybrids remained healthy.

The incubation period of the disease was also determined in Blackmore and Langdon Giants and Wrexham delphiniums grown from seeds, kept in a glasshouse during the summer and most of the winter, and inoculated during February, March, and April. To determine the effect of the disease on the flower parts, some of the delphiniums were inoculated before the spike developed and others after the spike began to appear. Each delphinium was exposed to one lot of 20 infective males, one species of leafhoppers being used on each plant. The number of

TABLE 2
INCUBATION PERIOD OF CALIFORNIA ASTER YELLOWS IN DELPHINIUM SEEDLINGS
INFECTED DURING JUNE BY FOUR VECTORS*

Variety of delphinium	Plants infected	Incubation period of disease	
		Range	Mean
	<i>number</i>	<i>days</i>	<i>days</i>
Blackmore and Langdon Giant.....	12	15-43	27.0
Chinese Azure Blue.....	12	15-17	16.3
Chinese Dark Blue.....	15	15-43	17.4
Chinese Blue Butterfly.....	14	15-43	19.6
All varieties.....	53	.....	19.5

* Each kind of delphinium was tested with all four vectors (mountain leafhopper, *Thamnotettix montanus*; geminate leafhopper, *T. geminatus*; and short-winged and long-winged aster leafhoppers, *Macrosteles divinus*), each plant being inoculated singly by one lot of 20 males of one vector.

TABLE 3
INCUBATION PERIOD OF CALIFORNIA-ASTER-YELLOWS DISEASE IN DELPHINIUMS*
INOCULATED DURING FEBRUARY TO APRIL OF THE SECOND YEAR'S GROWTH

Vector	Plants inoculated	Plants infected	Plants healthy	Incubation period of disease	
				Range	Mean
Delphiniums inoculated before spikes developed					
	number	number	number	days	days
Mountain leafhopper (<i>Thamnotettix montanus</i>).....	6	6	0	29-51	43.7
Geminate leafhopper (<i>T. geminatus</i>).....	5	5	0	27-81	59.0
Short-winged aster leafhopper (<i>Macrosteles divinus</i>).....	11	7	4	19-81	45.9
Long-winged aster leafhopper (<i>M. divinus</i>)....	7	7	0	22-43	30.1
All vectors.....	29	25	4	.....	43.5
Delphiniums inoculated after spikes developed					
	number	number	number	days	days
Mountain leafhopper (<i>T. montanus</i>).....	5	5	0	29-66	45.8
Geminate leafhopper (<i>T. geminatus</i>).....	5	4	1	28-44	32.0
Short-winged aster leafhopper (<i>M. divinus</i>)....	5	0	5	.....	.....
Long-winged aster leafhopper (<i>M. divinus</i>)....	5	5	0	28-106	55.6
All vectors.....	20	14	6	.....	45.0

* Blackmore and Langdon Giants and Wrexham.

days from the inoculation of the plant until the youngest leaves at the crown of the plant became chlorotic or until green abnormal flower parts developed was considered as the incubation period of the disease; this is shown in table 3. The check plants of both varieties remained healthy.

A comparison of the results obtained in tables 2 and 3 shows that the average incubation periods of the disease in delphinium seedlings infected during June of the first season's growth are shorter than in delphiniums inoculated during February, March, and April during the second year's growth. Temperature and thrifty or vigorous growth probably play important roles in the duration of the incubation period of the disease.

TABLE 4

SUMMARY OF RECOVERY OF CALIFORNIA-ASTER-YELLOWS VIRUS BY EACH VECTOR FROM NATURALLY AND EXPERIMENTALLY INFECTED DELPHINIUMS WHEN TRANSFERRED TO HEALTHY ASTER OR CELERY PLANTS

Vector	Delphiniums tested	Delphiniums from which virus was recovered	Percentage recovery of virus			
			From naturally infected delphiniums (table 1)	From experimentally infected delphiniums	From delphiniums in which incubation period was determined (tables 2, 3)	Weighted mean
	number	number	per cent	per cent	per cent	per cent
Mountain leafhopper (<i>Thamnotettix montanus</i>).....	71	13	15.1	18.5	27.3	18.3
Geminate leafhopper (<i>T. geminatus</i>).....	56	8	4.1	15.0	33.3	14.3
Short-winged aster leafhopper (<i>Macrosteles divisius</i>).....	104	4	2.2	9.4	0.0	3.8
Long-winged aster leafhopper (<i>M. divisius</i>).....	94	11	18.6	7.1	11.6	11.7

The infection of delphiniums by four vectors during the second year's growth before spikes appeared was 86.2 per cent and after spikes developed was 70.0 per cent.

Recovery of Virus from Experimentally Infected Delphiniums.—The virus was recovered from experimentally infected delphinium varieties or hybrids, including those plants in which the incubation period of disease was determined. The percentages of recovery of the virus by each vector from naturally and experimentally infected delphinium are shown in table 4, together with the number of recoveries of the virus with each vector and the total number of trials from which the average percentages were computed.

RESERVOIRS OF VIRUS

It is evident that perennial delphiniums serve as reservoirs of the aster-yellows virus. Some commercial growers practice roguing of diseased delphiniums from their fields but pay no attention to the weed reservoirs of the virus. Prickly sow thistle (*Sonchus asper*) growing among delphiniums and along the margin of the fields near Capitola

was commonly found to be naturally infected with aster yellows. Cheese-weed (*Malva parviflora*) was demonstrated to be naturally infected with the disease near Mt. Eden. A large number of weeds have been experimentally infected and many weeds have been demonstrated to be naturally infected with the virus.

CONTROL

Commercial delphinium growers plant seeds in seedbeds or cold frames. An examination of delphinium seedlings grown in seedbeds near Hayward showed the presence of the mountain leafhopper on December 22, 1938, but the geminate leafhopper was not collected; the latter may winter over in the egg stage. Aster yellows and other virus diseases of delphinium were common in cold frames and increased until they were transplanted in the field. Each virus-diseased delphinium transplanted in the field is a source of spread to healthy plants by insects. One grower raised delphinium seedlings in the cold frames under muslin covers to keep out leafhoppers and aphids. Among these seedlings, examined at intervals of 2 weeks until they were transplanted in the field, not a single virus-diseased plant was found.

One commercial grower practiced roguing of diseased delphiniums, and his fields were kept free from weeds, but delphinium aster yellows continued to appear. The mountain leafhopper was extremely abundant in delphinium fields during the summer and autumn in this district.

The weeds on which the four vectors of the aster-yellows virus complete their life histories under greenhouse conditions are being investigated. Field investigations must be undertaken to find the breeding plants of the mountain and geminate leafhoppers and to learn when the flights into the delphinium fields occur, before a spray program can be undertaken. One commercial grower began spraying operations during the spring, but not a single vector of the virus was captured by sweeping delphiniums with an insect net during that season.

The failure of delphiniums grown in home gardens sometimes can be attributed to diseased plants purchased from retail dealers and not always to the spread of the virus by leafhopper vectors after transplanting. All delphinium seedlings grown in flats offered for sale by one dealer in Oakland showed typical symptoms of aster yellows. During the spring of 1937, delphinium seedlings grown in flats were purchased from retail dealers and nurseries in Berkeley and San Pablo and were kept under observation in a glasshouse, but all plants remained healthy. Perennial delphiniums in nurseries in these two localities were usually free from aster yellows. One commercial grower in Berkeley, familiar with some symptoms of aster yellows, rogued the diseased plants.

GEOGRAPHIC RANGE OF VIRUS AND VECTORS

Discussions of host-range differences of California and New York aster yellows, overlapping host ranges, and strains of aster-yellows viruses have been published in previous papers by Kunkel (8), Severin (15), Severin and Haasis (24), and Smith (26). The results of experiments with the aster-yellows virus from eastern, middle-western, and western states have also been reported in a previous paper (15), and this investigation has been continued on host plants of aster yellows from other western states. The identity of the virus in other western states and the distribution of the most important vectors of the aster-yellows virus to delphinium may be worthy of discussion.

Utah.—Linford (33, 34) described typical symptoms of aster yellows on delphinium and also found aster yellows and a "virus-yellows" disease on celery in various localities in Utah.

Severin (15) demonstrated that the virus of celery yellows from Utah is probably identical with the California-aster-yellows virus.

Washington.—Heald and Burnett (6), mentioned previously, described typical symptoms of delphinium aster yellows occurring in the State of Washington. In a later paper, Burnett (2) reported that there was an excessive proliferation of the flowering stalks, which produced a bunchy witches' broom appearance. The flowering parts failed to develop normally but produced a characteristic leafy proliferation varying from slightly greenish flowers to pale-green leafy structures.

Heald⁶ has never observed aster yellows in the State of Washington, and he is not convinced that delphinium aster yellows of California is identical with the disease in Washington. He states that juice inoculation from diseased to healthy delphinium plants failed to produce the proliferated inflorescence showing virecence or greening of the flowering parts. But the aster-yellows virus can only be transmitted by leafhopper vectors and by grafting and budding; it is not transmissible by juice inoculation. All attempts at this station to infect healthy Wrexham delphinium, aster, and celery plants grown from seeds by sap inoculation with the carborundum method (12) were failures. The inoculated delphiniums were kept under observation until the blossoming period, but none developed abnormal, green flower parts.

Glen A. Huber, Western Washington Experiment Station, Puyallup, Washington, sent 1 delphinium, 3 aster, and 2 celery plants showing typical symptoms of aster yellows. Attempts were made to recover the virus from these naturally infected host plants by means of previously noninfective leafhoppers and to transfer it to healthy seed-grown plants.

⁶ Heald, F. D., in a personal interview.

Previously noninfective mountain leafhoppers recovered the virus from the naturally infected delphinium from Washington and transferred it to healthy celery plants. The virus was recovered from the experimentally infected celery plants by means of short-winged aster leafhoppers and transferred to healthy asters. Lots of 20 previously noninfective mountain leafhoppers, after feeding on the experimentally infected celery plants, were transferred to 10 healthy Pacific Giant second-year delphiniums. Three of the 10 inoculated plants developed green, abnormal flowers, numerous short chlorotic shoots grew from the crown of 5 infected delphiniums after the blossoming period, and 2 plants remained healthy. One lot each of previously noninfective short-winged and long-winged aster leafhoppers failed to recover the virus from the naturally infected delphinium and transfer it to healthy delphiniums. The delphinium plant from Washington died before further tests could be made.

Previously noninfective short-winged aster leafhoppers recovered the virus from the 3 naturally infected asters from Washington and transferred it to healthy aster and celery plants and from the experimentally infected celery plants back to asters. Repeated lots of short-winged aster leafhoppers bred on asters experimentally infected with the virus from the 3 naturally infected asters transmitted the virus to 5 Pacific Giant delphiniums; 2 plants developed abnormal flowers with green floral parts, and from the crown of 3 delphiniums grew dense clusters of short, yellow shoots after the flowering period.

The virus was also recovered from the 2 naturally infected celery plants from Washington and transferred to healthy aster and celery plants and from experimentally infected asters back to celery plants. Lots of previously noninfective geminate leafhoppers after feeding on the 2 naturally infected celery plants were transferred to 6 healthy Pacific Giant two-year-old delphiniums; 1 plant showed the green, abnormal inflorescence, and 5 developed numerous chlorotic shoots from the crowns after the blossoming period. The virus from delphinium stunt, and from aster and celery yellows from Washington is probably identical with the California aster-yellows virus.

Colorado.—C. M. Tompkins sent 9 aster-yellows plants from Brighton, Colorado. The virus was transferred from the diseased asters by short-winged and long-winged aster leafhoppers to 9 healthy aster and 3 healthy celery plants. The results indicate that the California-aster-yellows virus occurs in Colorado.

Oregon.—C. M. Tompkins sent 6 aster-yellows plants from Corvallis, Oregon. The virus was transferred by previously noninfective short-winged aster leafhoppers from the diseased asters to 5 healthy aster and

4 healthy celery plants. Thus the California-aster-yellows virus occurs in Oregon.

B. F. Dana, Corvallis, Oregon, sent a delphinium showing phyllody and virescence, but the plant died before any tests could be made.

Wyoming.—At the request of P. Brierly, United States Horticultural Station, Beltsville, Maryland, G. W. Bohn sent aster-yellows plants from Cheyenne, Wyoming. Previously noninfective short-winged and long-winged aster leafhoppers and the mountain leafhopper recovered the virus from 7 diseased asters from Cheyenne and transferred it to 11 healthy aster and 5 healthy celery plants. The virus was recovered from the 3 experimentally infected celery plants and transferred back to asters. These tests indicate that the California-aster-yellows virus also occurs in Wyoming.

Idaho.—At the request of E. C. Blodgett, Idaho Agricultural Experiment Station, C. D. Miller, Mullan, Idaho, sent 2 delphiniums showing witches' broom. Previously noninfective geminate leafhoppers transmitted the virus from the 2 diseased plants to 6 of 11 healthy two-year-old Pacific strain delphiniums but mountain leafhoppers failed to infect 15 delphiniums of the same variety.

Hungerford's (35) description of some of the symptoms on delphinium in Idaho are similar to those observed on delphinium naturally and experimentally infected with the aster-yellows virus in California. He states that the aborted flowering parts were very much dwarfed, but he does not mention the green leafy structures representing abnormal flower parts.

There was some variation in symptoms which developed on delphiniums experimentally infected with virus from Idaho. An apical proliferation of the spike developed with numerous 3-lobed green, leafy structures, or single-lobed leaves arranged in a rosette surrounding extremely dwarfed floral organs, or short shoots developed from the spike with linear leaves and an apical leafy cluster surrounding dwarfed flower parts.

Attempts were made to transmit the virus by means of the mountain, geminate, and short-winged and long-winged aster leafhoppers from the 2 naturally infected delphiniums from Idaho and delphiniums experimentally infected with virus from there, to healthy aster, celery, and carrot plants; but all were failures.

Severin (15) reported the transfer of an aster-yellows virus by means of previously noninfective short-winged aster leafhoppers from naturally infected carrots sent from Idaho to healthy carrots, but not to healthy aster and celery plants. From a second shipment of naturally infected carrots from Idaho, the virus was transferred to 3 of 61 celery

plants, but the virus was not recovered and transferred to asters from the 3 celery plants showing typical symptoms of yellows.

C. F. Henderson, of the United States Bureau of Entomology and Plant Quarantine, sent a third shipment of diseased carrots from Twin Falls, Idaho. The virus was not transferred from 10 naturally infected carrots by means of previously noninfective short-winged aster leafhoppers to 20 healthy aster and 20 healthy celery plants.

Henderson also sent 12 celery plants from Idaho, each showing a twisting of the central petioles, a symptom of California aster yellows. Previously noninfective short-winged aster leafhoppers failed to transfer the virus from the diseased celery plants to any of 12 healthy celery and 24 healthy aster plants.

The aster-yellows virus in naturally infected delphiniums, carrots, and celery from Idaho, therefore, has not been proved to be the California-aster-yellows virus.

Mountain Leafhopper.—The mountain leafhopper, *Thamnotettix montanus* Van D. has been recorded from British Columbia (28), Washington (31, 32), Oregon (32), California (29, 32), Nevada (3), Idaho*, Utah (7), Colorado (4, 28) and probably occurs in most of the western states.

Geminate Leafhopper.—The geminate leafhopper, *Thamnotettix geminatus* Van D. has been recorded from Colorado (4, 27), Idaho (see footnote 6), Utah (7), California (29, 30, 31, 32), Washington (11), and Alaska (1). Osborn (11) reported that it occurred in such numbers upon clover, alfalfa, and timothy in the State of Washington, especially Pullman, as to threaten to become destructive.

It is evident that one or both of the important vectors of the aster-yellows virus to delphinium in California occur also in Washington, Oregon, Idaho, and Utah, in which states the disease of delphinium resembling aster yellows is known to occur.

Delphinium "stunt" has been reported to occur in New York (36), but the mountain leafhopper and the geminate leafhopper do not occur in that state. The short-winged aster leafhopper occurs in New York and it may be possible that the virus of New York aster yellows produces phyllody and virescence in delphinium.

SUMMARY

A virus disease of garden varieties of perennial delphiniums is caused by the virus of California aster yellows. The delay in the discovery of the identity of the virus was caused by the fact that the short-winged

* Several shipments of the mountain and geminate leafhoppers were received from Twin Falls, Idaho, collected by C. F. Henderson.

aster leafhopper, *Macrosteles divinus* (Uhl.), rarely recovers the virus from diseased delphiniums. Delphinium is an unfavorable food plant of the short-winged and long-winged aster leafhoppers; some of the leafhoppers died within 4 to 6 hours and most of them within 24 hours.

The main abnormalities resulting from aster yellows on delphiniums may be summarized as follows: (1) dwarfing of plants and a bunched growth of short stems; (2) a general yellowing of the foliage; (3) phyllody, or the tendency of the floral organs to resemble leafy structures, and (4) virescence, or the replacement of floral pigments by chlorophyll.

The mountain leafhopper, *Thamnotettix montanus* Van D., and the geminate leafhopper, *T. geminatus* Van D., are the most important vectors of the virus to delphinium, and both species breed on this host plant under natural conditions. Adults of both species of leafhoppers were collected on naturally infected delphiniums and transferred to healthy seedlings; the mountain leafhopper transmitted the virus to 84.6 and the geminate leafhopper to 92.3 per cent of the plants. The average percentage of experimental infection of delphiniums by four vectors of the virus was as follows: two-year-old delphiniums before the spikes appeared, 86.2, and after the spikes developed, 70 per cent. The average percentages of the recovery of the virus from naturally and experimentally infected delphiniums by the different vectors were as follows: mountain leafhopper 18.3, geminate leafhopper 14.3, short-winged aster leafhopper 3.8, and long-winged aster leafhopper 11.7.

The incubation periods of the disease in seedlings of four delphinium varieties infected during June by four vectors averaged 19.5 days; in delphiniums infected during the second year in February, March, and April before spikes appeared averaged 43.5; and after spikes developed averaged 45.0 days. Delphiniums infected after the spikes appeared during the second year sometimes failed to produce green flowers with abnormal floral parts, but such plants developed a dense cluster of short, yellow shoots from the crown after the blossoming period.

The geographical range of the California-aster-yellows virus so far determined includes the following states: Oregon, Washington, Utah, Wyoming, and Colorado. The disease of delphinium resembling aster yellows is known to occur in Oregon, Washington, Utah, and Idaho, in which states either the mountain or the geminate leafhopper or both of these important vectors of the virus are known to occur.

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APPENDIX TO CITATIONS

Brief notes of the occurrence of delphinium virus diseases in the United States have appeared in the *Plant Disease Reporter*.⁷ Frequently the collaborators of these reports were not mentioned, and it was found more convenient to list them in the chronological order rather than under the name of collaborators and editors.

33. THE PLANT DISEASE REPORTER SUP. 59:111. 1927.

34. THE PLANT DISEASE REPORTER SUP. 65:420. 1927.

35. THE PLANT DISEASE REPORTER 17:5. 1933.

36. THE PLANT DISEASE REPORTER SUP. 90:135. 1935.

37. THE PLANT DISEASE REPORTER SUP. 96:268-69. 1936.

38. THE PLANT DISEASE REPORTER SUP. 110:263. 1938.

⁷ A mimeographed pamphlet issued by the United States Department of Agriculture Bureau of Plant Industry.

PLATES



Plate I.— *A*, One shoot from a dense cluster about 6 inches high showing lateral or axillary shoots with bunched, abnormal leaves, and elongated, chlorotic petioles, also linear or filamentous leaves and threadlike petioles; *B*, Wrexham delphinium seedling experimentally infected with aster yellows showing greatly elongated, vertical, frequently curved, white petioles with dwarfed, chlorotic leaves; *C*, lower center, normal leaf with 3 lobes or divisions, others, abnormal leaves with lobes partly developed, or 1 or 2 lobes absent; *D*, naturally infected seedling showing symptoms similar to *B* except that the petioles were shorter and most of the leaves were cupped inward. The greatly elongated petioles, such as those in *B*, developed only when kept in cages in the greenhouse.

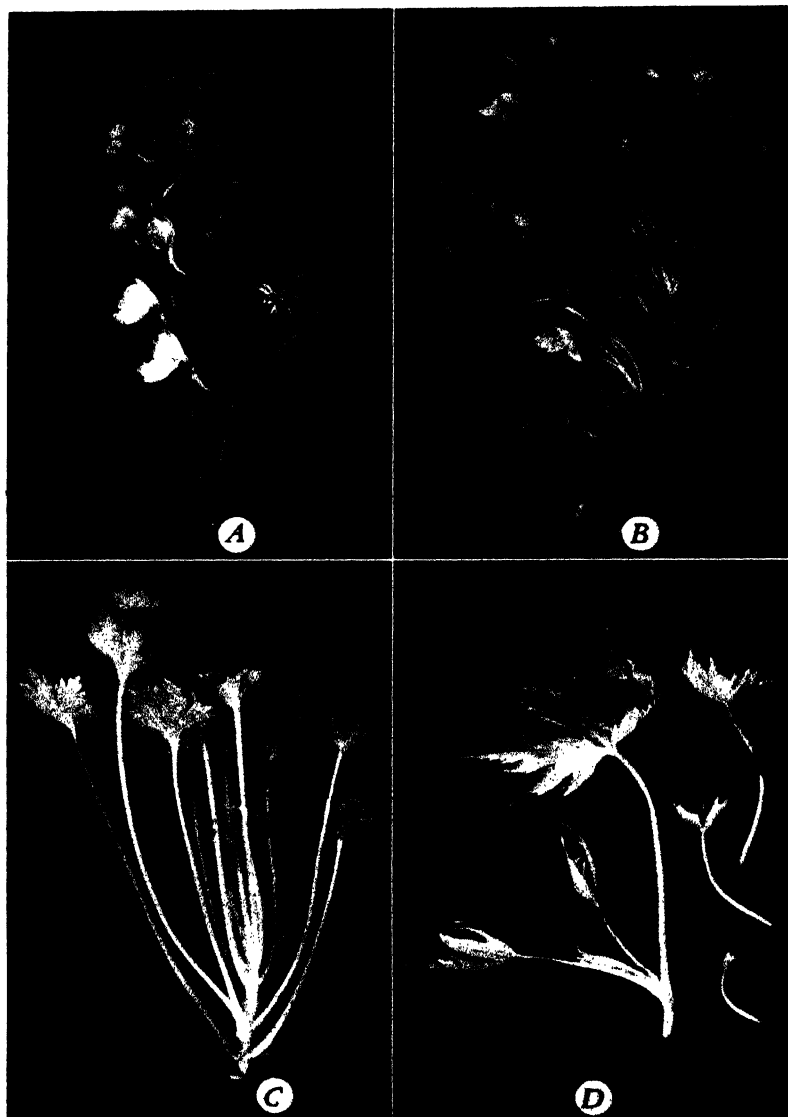


Plate 2.—*A*, Sectorial infection showing normal, colored flowers and abnormal flowers with green, leafy sepals and petals on opposite sides of the spike; *B*, cluster of green, leafy shoots which may remain dwarfed until the blossoming period, or may develop a slender spike—the petioles are elongated and yellow, often with chlorotic leaves cupped inward; *C*, one of many slender spikes—the petioles are elongated and yellow, often with chlorotic leaves cupped inward; *D*, chlorotic leaves from a delphinium plant experimentally infected with aster yellows during the second year before spike developed, showing cupped blades and curved petioles.



Plate 3.—Apical end of spikes with abnormal flowers from delphinium plants naturally infected with aster yellows; *A*, flower buds which were green; *B*, enlarged green, leafy sepals and dwarfed petals; *C*, replacement of carpels by petiolate leaflike structures or stems; *D*, left, lower flowers which were green instead of blue, upper flowers with elongated stamens and leafy, petiolate, partly opened carpels, which in some cases have lobes resembling ovules; right, two flowers with sepals, petals, carpels, and stamens replaced by green, leafy structures.

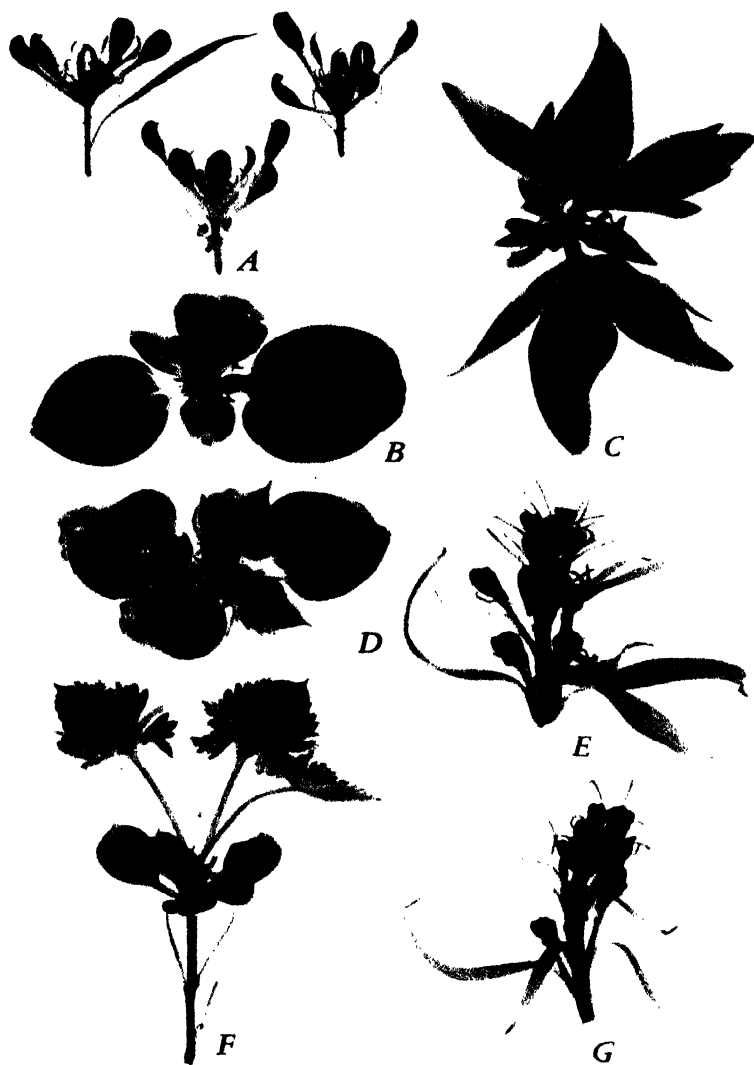


Plate 4.— Abnormal floral parts from delphiniums naturally and experimentally infected with California aster yellows: *A*, cupped sepals, dwarfed petals, and elongated stamens; *B*, enlarged sepals and abnormal floral parts; *C*, 3-lobed leaves and central dwarfed flower parts; *D*, *E*, enlarged, cupped sepals, dwarfed petals, and replacement of carpels by structures resembling leaves; *F*, structures resembling small flower buds; *G*, one stalked bud arising in the center of another bud.

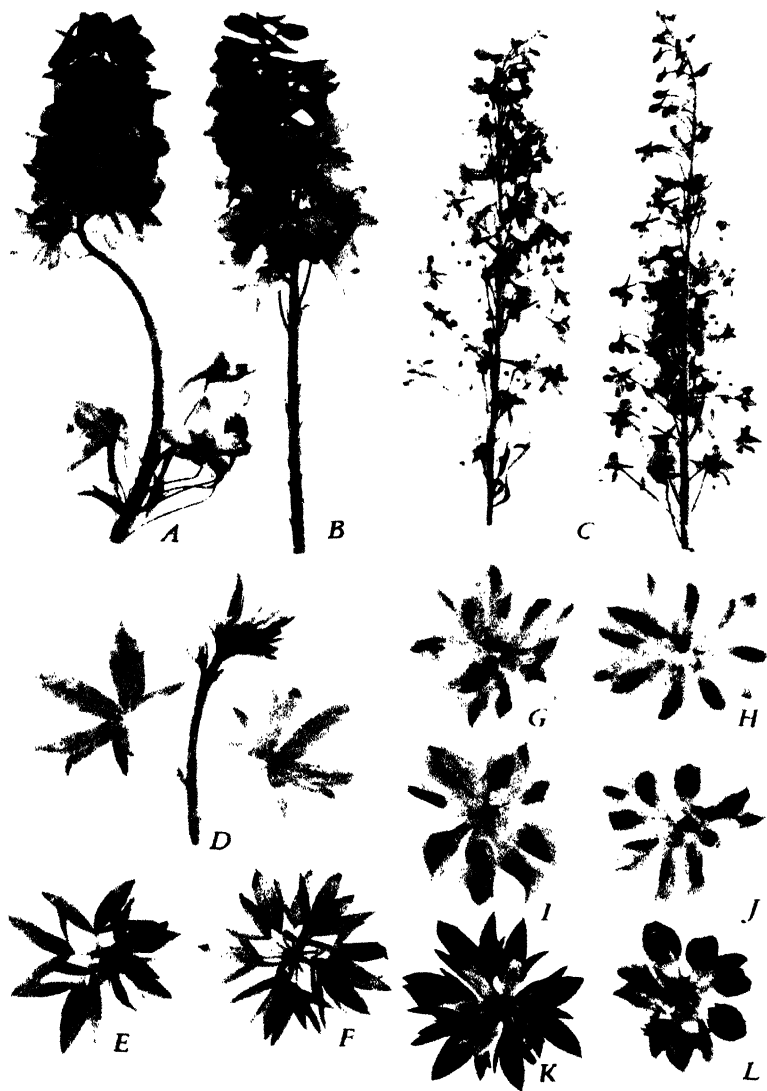


Plate 5 - Abnormal flowers of delphiniums naturally infected with California aster yellows: *A*, cluster of apparently normal flowers on the apical and basal regions of spike with the intermediate part bearing filamentous structures; *B*, cluster of flowers restricted to apical portion of spike; *C*, dwarfed flowers with elongated pedicels; *D*, spike showing apical cluster of abnormal flowers surrounded by dwarfed single-lobed leaves and with lower, normal divisions of leaves; *E*, *F*, rosettes with 3-lobed leaves surrounding undeveloped floral structures; *G*-*J*, flowers showing median green areas on petals; *K*, rosette composed of 3-lobed leaves, dwarfed sepals, and petals; *L*, rosette with cupped leaves and dwarfed petals.



Plate 6.—Proliferation of apical end of spike from delphiniums naturally infected with California aster yellows: *A*, dense cluster of leaves enclosing green flowers; *B*, cluster of leafy structures replacing normal sepals, petals, carpels, and stamens, with lower, normal-shaped leaves; *C*, linear structures representing abnormal floral parts with lower single-lobed leaves; *D*, bunched, tangled mass of flower parts; *E*, cluster of wilted leaves from fallen stalk still adhering to roots.



Plate 7.—Apical ends of spikes from delphiniums naturally infected with California aster yellows: *A*, central cluster of abnormal flowers with filamentous flower parts and dwarfed apical leaves surrounding abnormal green flowers; *B*, abnormal, green flowers with filamentous parts arranged and spaced on the spikes like those of healthy plants; *C*, dwarfed, green flowers with long pedicels on apical end of spike with lateral branches surrounded by linear leaves; *D*, numerous slender branches with dwarfed, abnormal, green flowers suggesting a witches' broom appearance.



Plate 8.—Dreer's De Luxe delphinium naturally infected with California aster yellows with necrotic symptoms on the stems, petioles, and blades, probably caused by secondary bacterial infections and not directly by the aster-yellows virus: *A*, black, necrotic streaks on stem and on some of the petioles; *B*, black, necrotic tissue on blade; *C*, black, necrotic areas at the attachment of some of the petioles and on some of the blades; *D*, stem showing small, brown, necrotic lesions; *E*, long necrotic streak; *F*, cracks; *G*, black lesions which girdle the stem; *H*, spike showing apical cluster of abnormal flowers, black stem, and dead leaves.

**CELERY CALICO ON PERENNIAL
DELPHINIUMS AND CERTAIN
OTHER HOST PLANTS**

HENRY H. P. SEVERIN

CELERY CALICO ON PERENNIAL DELPHINIUMS AND CERTAIN OTHER HOST PLANTS¹

HENRY H. P. SEVERIN²

INTRODUCTION

ONE OF THE viroses found in the course of the investigations of aster yellows on perennial delphiniums (4)³ proved to be transmissible by juice inoculation and showed symptoms resembling those of calico on celery. Calico was reported by Severin and Freitag in 1935 (5). In a later paper (6) they described and figured the symptoms of the disease. But the disease has not hitherto been reported on delphiniums or any other species of the family Ranunculaceae.

An investigation was accordingly undertaken to determine whether one of the naturally occurring viroses of perennial delphiniums was caused by the celery-calico virus. Studies were made of the variable symptoms of the disease on this host plant, the incubation period of the disease, the recovery of the virus, and the vectors. A number of hybrids and horticultural varieties of perennial delphiniums were tested for susceptibility to celery calico. A few other host plants of the virus are reported in this paper.

Delphiniums in the field in California were found to be frequently infected with more than one virosis—as, for example, with aster yellows and the disease reported in this paper. This situation greatly complicates the problem, especially since the symptoms of these viroses are extremely variable, even when they occur singly. Little progress can be made unless multiple viruses can be separated, and attempts were therefore made to work out methods for doing this in delphinium and also in tomato. Much confusion in the literature dealing with delphinium viroses is caused by the failure of some plant pathologists to recognize and separate multiple viruses in naturally infected plants.

Heald and Burnett (2), working with delphiniums infected with what they called “stunt” (aster yellows) (4), reported that some of the symptoms were reproduced by juice inoculation to healthy transplants and seedlings grown in the greenhouse, but that the inoculated plants did not develop the proliferated inflorescence and virescence shown by the naturally infected plants. They state, “It seems probable that all of the

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³ *Italic numbers in parentheses refer to “Literature Cited” at the end of this paper.*

observations are concerned with slightly different phases of a single disease although it is possible that more than a single virus disease is represented."

Burnett (1) states that healthy delphiniums inoculated with "macerated leaf tissue" from naturally infected delphiniums produced such symptoms as ringspot, necrosis, and chlorosis. Plants from which the virus was secured exhibited such symptoms as necrosis, chlorosis or yellowing, a witches'-broom effect, and a reversion of the floral parts to green, leafy structures. He assumed that a single virus produced extremely variable symptoms on delphinium and some other host plants, under different environmental conditions. In the present investigation, some of the host plants reported by Burnett for delphinium stunt were inoculated with celery-calico virus to test susceptibility and compare the symptoms with those described by Burnett.

MATERIAL AND METHODS

The sources of inoculum were delphinium, celery, cantaloupe, cucumber, Summer Crookneck squash, and tomato, all naturally infected with calico. The virus extract from these host plants was usually inoculated in the cotyledons of healthy cucumbers, and the virus was retained by repeated mechanical inoculation to cucumbers. Cucumbers were used because the symptoms developed rapidly on the cotyledons, often in 2 days. The carborundum method of inoculation described by Rawlins and Tompkins (3) was used.

The multiple viruses in naturally infected delphinium and tomato were separated by means of filter plants. The aster-yellows virus was separated from a virus complex in delphinium by means of previously noninfective leafhoppers.

SYMPTOMATOLOGY

The symptoms of celery calico on delphinium are very conspicuous in the field and can be noticed across three or four rows of plants. The basal or lower and intermediate leaves show pale-orange, amber, or lemon-yellow, irregular areas, *but the younger leaves never show symptoms of the disease.*

A closer examination of the leaves showing symptoms from perennial delphiniums naturally and experimentally infected with calico reveals a considerable amount of variation in the patterns. A few of the oldest leaves of infected seedlings may show irregular, chlorotic areas on some or all of the lobes or divisions (plate 1, A, B), or an entire leaf may assume a pale-orange or lemon color. Variations in the patterns may occur on the older leaves of the same plant, such as irregular discolora-

tions on one leaf (plate 1, *C*) and small green areas scattered in the chlorotic region of another leaf (plate 1, *D*). Such green islands in the pale-orange, amber, or lemon-yellow areas (plate 1, *F*) are reliable symptoms of calico on celery and other host plants. Sometimes a lower leaf of an infected delphinium seedling may show chlorotic or green streaks (plate 1, *E*; plate 2, *D*).

Both naturally and experimentally infected delphiniums frequently show line or ring patterns. The lines are often broken, consisting of a series of chlorotic dots or dashes (plate 2, *A*, *B*), or alternating green and yellow lines (plate 2, *C*). Ring patterns resembling ringspots may be composed of chlorotic dots enclosing green areas (plate 2, *E*); sometimes the chlorotic dots are arranged in groups. The rings may consist of concentric, alternating, yellow and green lines surrounding green centers (plate 2, *F*).

The Chinese varieties of delphiniums (*Delphinium grandiflorum*) developed chlorotic, lateral shoots and the linear segments of the blades were yellow and failed to develop the variable symptoms previously described.

The virus of calico causes breaking in the color of pansies and violas (plate 6, *K*), and this symptom is one method of identifying the virus; but the blossoms of naturally and experimentally infected delphinium were normal in appearance.

EXPERIMENTAL INFECTION

Since a considerable amount of variation occurs in the patterns on the leaves of delphinium plants naturally and experimentally infected with calico, inoculations of delphiniums were made with the virus extract from a number of naturally infected host plants obtained in various localities in California. Delphiniums showing symptoms of calico were collected in the San Francisco Bay district, Mt. Eden, Capitola, Hillsborough, Salinas, and Fresno. The expressed juice from delphiniums showing different calico patterns on the leaves was inoculated in healthy delphiniums, cucumber, and Turkish tobacco, and subinoculations were made from the last two plants back to healthy delphinium seedlings. Inoculations of healthy delphinium seedlings were also made with the virus extract from other naturally infected host plants of calico as follows: cantaloupe from Sacramento Pocket, celery from Milpitas, cucumber (plants and fruit) from San Pablo, Summer Crookneck squash (fruit) from Santa Cruz, and tomato from Berkeley. The results are shown in table 1. The inoculum from delphiniums and the various host plants of calico produced variable symptoms on the leaves of delphiniums regardless of the source of virus.

TABLE 1

INCUBATION PERIOD OF DISEASE IN DELPHINIUMS INOCULATED WITH VIRUS EXTRACT
FROM HOST PLANTS NATURALLY INFECTED WITH CALICO

Source of inoculum (host plant and district), delphinium variety inoculated, and date of inoculation (1936-1940)	Plants inoculated	Plants infected	Incubation period of disease in plants	
			Range	Mean
	<i>number</i>	<i>number</i>	<i>days</i>	<i>days</i>
From delphinium at Fresno:				
Into Wrexham delphinium:				
September 21.....	5	3	65-77	71.0
February 18.....	5	1	39	....
From delphinium at Berkeley:				
Into Wrexham delphinium:				
September 23.....	5	1	152	....
From delphinium at Montara:				
Into Wrexham delphinium:				
October 4.....	5	2	67-87	71.7
December 11.....	5	2	18-80	34.0
February 2.....	5	2	25-25	25.0
From delphinium at Colma:				
Into Wrexham delphinium:				
November 6.....	5	1	75	....
December 2.....	5	1	106	....
From cantaloupe at Sacramento Pocket:				
Into Wrexham delphinium, September 23.....	5	1	178	....
Into tall hybrid Bellamosum delphinium:				
March 5.....	5	1	40	....
From celery at Milpitas:				
Into Blackmore and Langdon delphinium:				
October 1.....	5	4	40-46	44.5
October 5.....	5	1	42	....
October 6.....	5	2	41-49	45.0
October 7.....	10	7	28-35	33.0
Into White Elatum (Summer Cloud) delphinium:				
October 7.....	5	1	28	....
From cucumber at San Pablo:				
Into Wrexham delphinium:				
March 24.....	5	4	39-55	47.0
From Summer Crookneck squash at Santa Cruz:				
Into Wrexham delphinium:				
September 23.....	5	3	131-159	145.3
From tomato at Berkeley:				
Into Wrexham delphinium:				
September 26.....	5	1	143	....
December 15.....	5	2	18-79	57.7

TABLE 2

LIST OF VARIETIES AND HYBRID DELPHINIUM SEEDLINGS EXPERIMENTALLY INFECTED WITH CELERY CALICO, INCUBATION PERIOD OF DISEASE, AND RECOVERY OF VIRUS

Delphinium variety or hybrid and date inoculated (1936-1940)	Delphiniums inoculated	Delphiniums infected	Incubation period of disease in delphiniums		Recovery of virus from infected delphiniums	
			Range	Mean	Cucumbers inoculated	Cucumbers infected
Blackmore and Langdon hybrids:	<i>number</i>	<i>number</i>	<i>days</i>	<i>days</i>	<i>number</i>	<i>number</i>
June 28.....	2	2	19-19	19 0	10	6
August 31.....	5	3	23-38	30 0	15	15
Belladonna tall hybrids:						
May 6.....	3	3	30-39	34 0	15	9
June 12.....	3	3	17-24	21 0	15	15
July 30.....	4	3	37-66	56 3	15	15
Chinenais grandiflorum var. album:						
June 12.....	5	5	26-43	34 0	25	25
Chinese Azure Blue:						
June 24.....	3	2	20-33	26 5	10	10
August 31.....	2	1	69		5	0
Chinese Dark Blue:						
June 12.....	5	5	43-43	43 0	25	25
Clivenden Beauty:						
June 12.....	5	5	15-31	22 5	25	25
Delphinium Parryi var. maritimum:						
November 25.....	1	1	—*	—*	5	5
Delphinium Zaidi:						
March 12.....	1	1	—*	—*	5	5
Dreer's De Luxe Art shades:						
June 12.....	5	5	15-28	20 8	25	25
Dreer's De Luxe Dark-Blue shades:						
June 12.....	5	5	16-43	25 0	25	25
September 17.....	1	1	52		5	5
October 15.....	3	3	—*	—*	15	15
Dreer's De Luxe Light-Blue shades:						
June 28.....	3	2	23-26	24 0	10	10
September 17.....	1	1	82		5	2
Dreer's De Luxe Mid-Blue shades:						
August 31.....	5	1	35		5	0
June 12.....	5	5	16-17	16 2	25	25
Dwarf Chinese Butterfly:						
June 12.....	5	2	15-28	21 5	10	10
English hybrids Deep-Blue shades:						
June 12.....	5	5	15-17	16 0	25	25
English hybrids Mid-Blue shades:						
June 12.....	5	3	15-17	15 7	15	15
October 15.....	5	1	41		5	5
English hybrids Pastel shades:						
June 28.....	3	3	15-26	21 0	15	15
Burpee's Floradale Giants Deep Blue:						
June 29.....	1	1	—*	—*	5	5
August 31.....	5	3	23-26	25 0	15	0
Burpee's Floradale Giants Light Blue:						
June 28.....	2	2	14-14	14 0	10	10
August 31.....	1	1	40		5	5
September 17.....	2	2	23-45	34 0	10	10
Burpee's Floradale Giants Mid Blue:						
June 24.....	3	3	15-31	21 0	15	0
August 31.....	5	3	23-40	32 3	15	0
September 17.....	1	1	52		5	5

* No symptoms, but virus recovered from infected delphiniums.

(Table concluded on next page)

TABLE 2—(Concluded)

Delphinium variety or hybrid and date inoculated (1936-1940)	Delphiniums inoculated	Delphiniums infected	Incubation period of disease in delphiniums		Recovery of virus from infected delphiniums	
			Range	Mean	Cucumbers inoculated	Cucumbers infected
	number	number	days	days	number	number
Burpee's Floradale Art or Pastel shades:						
October 2.....	4	4	—*	—*	20	20
October 15.....	1	1	24	....	5	4
Giant Single and Double hybrids:						
June 24.....	3	3	18-30	22.0	15	12
A. & M. Gold Medal hybrids:						
June 12.....	5	5	15-31	22.6	25	25
Gold Medal hybrids:						
June 24.....	5	4	12-15	13.0	20	20
September 17.....	1	1	52	....	5	5
October 15.....	4	1	—*	—*	5	2
Hardy larkspur (<i>Delphinium formosum</i>):						
June 12.....	5	5	15-21	17.2	25	25
August 31.....	5	3	23-35	27.0	15	15
Hybridum mixed:						
June 12.....	5	5	15-17	15.6	25	25
October 2.....	4	1	23	....	5	5
Iceberg:						
June 12.....	5	4	17-17	17.0	20	20
July 31.....	5	1	59	....	5	5
Improved Belladonna Clivenden Beauty:						
October 2.....	5	1	37	....	5	5
Improved English hybrids:						
June 24.....	5	4	12-30	19.6	20	20
September 17.....	1	1	45	....	5	5
October 15.....	2	2	—*	—*	10	4
November 25.....	1	1	—*	—*	5	4
Lady Guinevere:						
September 17.....	3	3	—*	—*	15	12
October 2.....	1	1	37	....	5	0
Lemon Gem:						
June 24.....	5	4	—*	—*	20	20
Burpee's Mammoth hybrids:						
June 24.....	5	5	11-14	12.0	25	25
New Hollyhock strain:						
September 17.....	3	3	28-45	33.7	15	15
Pacific Giant mixed:						
June 12.....	5	4	17-44	28.0	20	20
Pacific Giant White:						
June 12.....	5	3	23-31	26.3	15	15
June 12.....	2	2	—*	—*	10	4
September 17.....	2	2	63-63	63.0	10	10
September 17.....	3	3	—*	—*	15	15
A. & M. Sunbeam hybrids:						
June 24.....	5	5	16-16	16.0	25	25
Wrexham Hollyhock strain:						
September 17.....	2	2	28-63	45.5	10	10

* No symptoms, but virus recovered from infected delphiniums.

Varieties and Hybrids Inoculated.—The delphinium varieties and hybrids infected with the inoculum from various host plants naturally and experimentally with calico, are listed in tables 1 and 2. All delphiniums listed in these tables were seedlings except the Wrexham, or Hollyhock, variety (table 1), which was used after the second year's growth.

Incubation Period of the Disease.—The period from the date of inoculation until the orange or yellow discoloration, line, or ring patterns appeared on the basal leaves of delphinium seedlings was considered as the incubation period of the disease.

As indicated in tables 1 and 2, the incubation period of the disease varied from 11 to 178 days.

During the past year, Pacific-strain second-year delphiniums infected with calico were marked in the field in Berkeley, and it was noted that in the new shoots appearing from the ground after the old stock was cut off, symptoms on the leaves were slower to develop in the summer than in the spring, and still slower in the fall. During the past mild winter (1941–42), the leaves on the new shoots failed to show symptoms even after the spikes developed.

Recovery of the Virus.—An attempt was made to recover the virus from some of the experimentally infected delphiniums during the second year. Fifteen delphinium seedlings were selected which showed prominent and characteristic symptoms of the disease and from which the virus had been recovered during the first year. All of the foliage was removed during November, and the roots were given a rest period during the winter. After a period of 9 to 12 months had elapsed since the seedlings had been inoculated, the juice was expressed from the new shoots and inoculated in Turkish tobacco and cucumber plants. The virus was not recovered from 1 delphinium plant which showed typical symptoms of the disease during the first and second years. But it was recovered from the other 14 experimentally infected plants, 4 of which failed to show symptoms of the disease during the second year. Evidently some infected delphinium plants are symptomless carriers of the disease during the second year.

Delphinium plants which appeared to be infected with a cucumber mosaic were found under natural conditions; others revealed a mottling of the leaves resembling a mosaic disease, and many showed dried, brown flowers with or without malformed leaves. Repeated cross inoculations were made from these abnormal plants (transplanted in a glass-house) to healthy delphinium seedlings, but all attempts to reproduce the symptoms were failures. Frequently these abnormal plants also showed symptoms of aster yellows or sometimes calico. The virus of

calico was sometimes recovered from these abnormal plants, which failed to show symptoms of calico on the leaves. Evidently some of these abnormal plants were symptomless carriers of calico and served as reservoirs of the virus. It is not to be inferred, however, that the calico virus produced the abnormalities.

HOST RANGE

In this paper the symptoms of calico on a few cultivated plants are described, and compared with the symptoms described by Burnett (1). According to Burnett (1) the host range of delphinium "stunt" (aster yellows) includes 12 species of plants: Connecticut Havana tobacco, tomato, cucumber, petunia, zinnia, and 7 species of weeds. The source of virus was from naturally infected delphiniums transplanted in boxes in the greenhouse.

Tobacco.—The earliest symptom of calico on Turkish tobacco, *Nicotiana Tabacum*, infected with the virus extract from diseased celery or delphinium plants is broken, concentric, necrotic, circles (plate 3, *A*) which appear in 4 days or longer on the inoculated leaves. The circles are composed of necrotic dots (plate 3, *B*) when examined under a binocular microscope. The next symptom on the inoculated leaves is the oak-leaf pattern (plate 3, *C*) consisting of necrotic dots and lines. A striking oak-leaf pattern also developed on the leaves of *N. Langsdorfii* (plate 3, *D*). In the advanced stage of the disease, the entire inoculated leaf may show variable ring and oak-leaf patterns (plate 3, *E, F*). The necrotic ring and oak-leaf patterns are confined usually to the inoculated leaves and sometimes to a few subsequently developing leaves. As infected Turkish tobacco plants grow older, the inoculated leaves and those above the inoculated ones exhibit intervenal, circular, chlorotic areas (plate 4, *A*), which coalesce and form irregular, blotchy mottle (plate 4, *B*) that extend to near the midrib (plate 4, *C, D*). The leaves below the flowers may show faint, chlorotic areas (plate 4, *E, F, G*) or no symptoms.

Burnett (1) described and figured a white, necrotic, etching, with ring-and-line pattern of variable forms confined to the first few leaves on Connecticut Havana tobacco, *Nicotiana Tabacum*, as a result of inoculation from delphiniums affected with "stunt." He also described and figured a blotchy, irregular, usually intervenal mottle which may coalesce to form extensive chlorotic areas involving the major part of the older leaves. These symptoms correspond to those produced by the virus of calico on Turkish tobacco. This indicates that Burnett probably was transmitting the calico virus from the delphiniums affected by a combination of the aster-yellows and calico viruses, since some of the symptoms on delphiniums were those of aster yellows (see p. 412).

Valleau (7) described and figured a ring-and-line pattern resembling calico on the leaves of Turkish tobacco rubbed with the extract from a virus disease of delphinium in Kentucky.

White Spine Cucumber.—The first symptom that often develops on the cotyledons of infected seedlings of White Spine cucumber, *Cucumis sativus*, 2 days or longer after inoculation, is large, pale-green circular areas which later are surrounded by chlorotic rings (plate 5, A). The next symptom which appears on the younger leaves is numerous, small, circular, chlorotic spots (plate 5, B), which coalesce and form irregular, yellow areas (plate 5, C) that spread over the leaves. The petiole is bent and the youngest leaves are sometimes cupped inward. In a late stage of the disease, the older leaves become chlorotic except for bands of green tissue extending along some of the veins (plate 5, D). Cucumber fruits show irregular, chlorotic mottling (plate 5, E, F).

The symptoms on cucumber described by Burnett (1) as resulting from inoculation from delphinium are not those produced by the virus of calico. He reports that the fruit which matured failed to show evident symptoms.

Marglobe Tomato.—The symptoms of calico on Marglobe tomato plants, *Lycopersicon esculentum*, begin on the lower or older leaves of tomato plants, and appear as an orange discoloration on a portion of the leaflets (plate 6, A) and spread until the entire leaf is affected. A progressive orange discoloration of the lower leaves on the main stem and lateral branches continues, but the younger leaves remain green. This symptom of calico may be readily overlooked, since a natural yellowing of the lower leaves occurs on healthy check or control plants, especially on old plants. Sometimes green islands occur in the orange discoloration.

The symptoms on tomato described by Burnett (1) do not correspond to those produced by the virus of calico. He states, however, that fern leaf is not caused by the delphinium virus alone.

Rosy Morn Petunia.—The first symptom of the disease which appeared on Rosy Morn petunia, *Petunia hybrida*, was a clearing of the veins (plate 6, C) 6 days or longer after inoculation with the virus extract from delphinium infected with celery calico. In the later stage of the disease, the basal or lower leaves become orange in color; sometimes the tissue along the midrib remains green. The older ascending leaves develop variable orange and green patterns (plate 6, F, G, H), sometimes deep-green blotches in the chlorotic tissue, or an oak-leaf pattern along the midrib and lateral veins (plate 6, D, E).

Symptoms were not evident on *Petunia hybrida*, according to Burnett, (1) but the virus was recovered when subinoculations were made to tobacco plants.

MULTIPLE VIRUSES

It seems likely that Burnett (1) was dealing with multiple viruses in his host-range studies. He unquestionably failed to reproduce the symptoms of aster yellows on delphinium by juice inoculation since this virus is inactivated in expressed juice (4). Possibly the inoculum from naturally infected delphiniums may have contained the calico virus. His inoculations into Connecticut Havana tobacco indicate this to be the case but his inoculations into other host plants do not substantiate this interpretation.

A delphinium plant sometimes contains both calico and aster-yellows viruses in the field, and the inoculum from such a plant produces infection of calico but not aster yellows. The aster-yellows virus was recovered from the virus complex in delphinium plants by previously noninfective mountain leafhoppers, *Thamnotettix montanus* Van D., geminate leafhoppers, *T. geminatus* Van D., and the long-winged aster leafhoppers, *Macrostelus divinus* (Uhl.).

Tomato plants are frequently infected with a mixture of viruses under natural conditions; for example, ordinary tobacco mosaic identical with tomato mosaic (tobacco virus 1) and calico. The virus of ordinary tobacco mosaic sometimes produces symptoms described as fern leaf, filiform leaf, or shoestring leaf (plate 6, I), when young, slow-growing tomato plants are inoculated and kept under low temperatures and light intensity, but the calico separated from the virus complex rarely induces such symptoms. When the multiple viruses in the tomato extract are inoculated in cucumber plants, tobacco mosaic is filtered out and the calico virus is retained.

GEOGRAPHIC RANGE OF THE VIRUS

California.—Perennial delphiniums naturally infected with the celery-calico virus were collected in the San Francisco Bay districts, in the Santa Clara, Salinas, and San Joaquin valleys, and in Capitola, Montara, and Hillsborough. Celery calico has been found in all of the large celery districts of California.

Washington.—G. A. Huber, Western Washington Experiment Station, Puyallup, Washington, kindly sent 2 celery plants showing typical symptoms of calico. The virus extract from these 2 plants was mechanically inoculated into five known hosts of celery calico, 5 plants being used in each test. The numbers of these that became infected were: Wrexham delphinium 5, celery 2, White Spine cucumber 5, Turkish tobacco 3, and *Nicotiana glutinosa* 3. It is evident that the virus of celery calico from Washington is identical with that from California.

Idaho.—One of two delphinium witches' broom (aster yellows) (4) sent from Mullan, Idaho, by C. D. Miller, showed typical symptoms of calico while the other plant was a symptomless carrier of the virus. The virus extract from these two plants inoculated into 5 known hosts of celery calico produced the following infections: 5 Blackmore and Langdon delphiniums, 18 celery, 29 White Spine cucumbers, 5 Turkish tobacco, and 5 *Nicotiana glutinosa*. The results indicate that the virus separated from this virus complex is probably identical with the virus of celery calico from California and the range of the virus may thus be tentatively extended to Idaho.

APHID VECTORS

The natural occurrence of colonies of aphids on delphinium plants has never been observed in California by the author. Occasional winged aphids were found on delphiniums under natural conditions, but most of these were dead.

It was difficult to infect delphinium seedlings with calico by means of any of the species of aphids tested, even though each plant was inoculated with the virus by two lots of 40 aphids each. The following species of aphids reared on celery infected with calico, did, however, transmit the virus to healthy delphinium seedlings to which they were transferred:

Celery leaf aphid, *Aphis apigraveolens* Essig

Celery aphid, *Aphis apii* Theobald

Rusty-banded aphid, *Aphis ferruginea-striata* Essig

Cotton, or melon, aphid, *Aphis gossypii* Glover

Erigeron root aphid, *Aphis middletonii* Thomas

Lily aphid, *Myzus circumflexus* (Buck)

Foxglove aphid, *Myzus convolvuli* (Kalt.)

Green peach aphid, *Myzus persicae* (Sulz.)

Honeysuckle aphid, *Rhopalosiphum melliferum* (Hottes)

The virus was recovered by previously noninfective cotton, or melon, aphids, *Aphis gossypii*, from a delphinium plant infected by this species of aphid and transferred to a healthy celery plant. No difficulty was experienced in recovering the virus from delphiniums infected with the nine listed species of aphids by mechanical inoculation of the virus extract into healthy delphinium, celery, and cucumber plants.

Winged green peach aphids occasionally were taken on delphiniums grown in the field, and an attempt was made to recover the virus by previously noninfective aphids from naturally infected delphiniums and transfer it to healthy plants. The virus was transmitted to 2 of the 17 plants that were inoculated. A high mortality of the aphids occurred on delphiniums.

SUMMARY

A virus disease of perennial delphinium has been proved to be celery calico.

The symptoms of celery calico on delphiniums are confined to the basal and intermediate leaves and are variable, including pale-yellow, amber, or lemon-yellow areas, or line or ring patterns. The virus does not cause abnormal flowers or breaking in the color of the flowers.

The incubation period of the disease ranged from 11 to 178 days.

Delphiniums either naturally or experimentally infected during the first year may be symptomless carriers of the virus during the second year.

Calico is often associated with aster yellows in delphiniums under natural conditions, and the inoculum from such plants produces infection of calico but not aster yellows. The aster-yellows virus was recovered from the virus complex by three species of leafhoppers.

Tomato plants are sometimes infected with a mixture of viruses. Cucumber plants, when inoculated with the virus extract, filter out ordinary tobacco mosaic virus and retain the calico virus.

Nine species of aphids were demonstrated to be vectors of the virus.

ACKNOWLEDGMENTS

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PLATES



Plate 1. Delphinium leaves showing symptoms of celery calico from plants grown from seeds and infected with the virus by mechanical inoculation: *A*, leaf showing irregular, yellow discolorations on three lobes or divisions from a seedling infected with the virus extract from Summer Crookneck squash (fruit) naturally infected with calico; *B*, leaf from a delphinium seedling inoculated with the juice extracted from the same squash, showing yellow areas extending into all lobes; *C*, *D*, two leaves showing variation in symptoms from the same delphinium seedling inoculated with the juice from celery calico, *C* showing leaf discoloration and *D* green areas in the chlorotic regions; *E*, leaf showing yellow speckling and streaks from a seedling inoculated with the virus extract from a tomato plant naturally infected with calico; *F*, leaf showing green islands in the lemon yellow areas from a seedling inoculated with the expressed juice from a delphinium plant naturally infected with the disease.

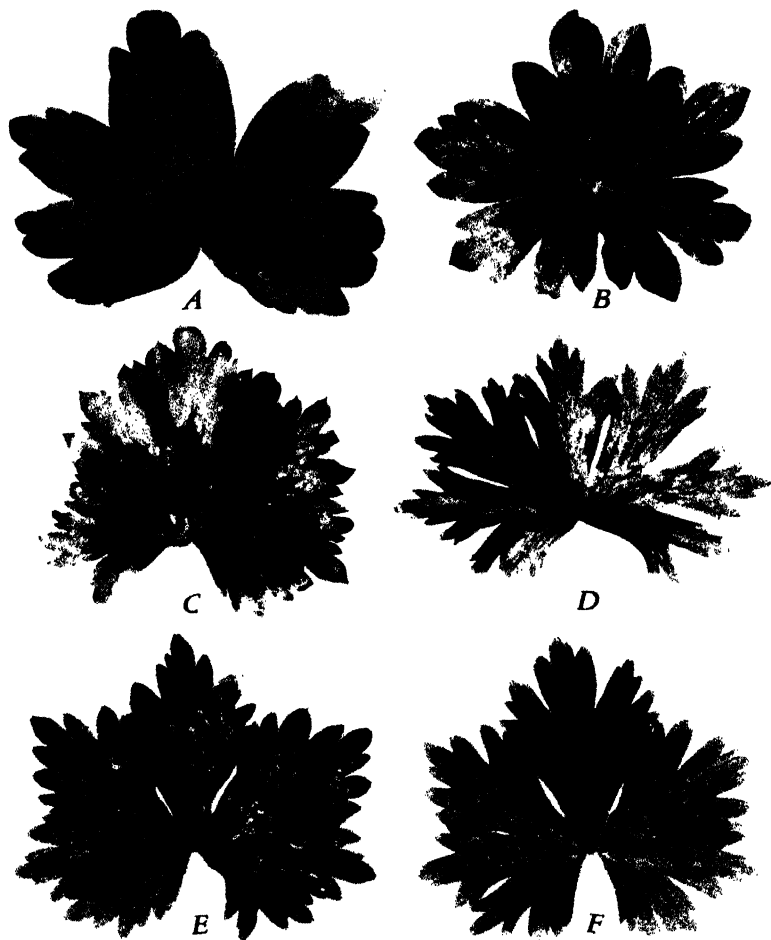


Plate 2.—Delphinium leaves showing symptoms of celery calico from plants grown from seeds and experimentally infected by mechanical inoculation: *A, B*, leaves from delphinium seedlings inoculated with the virus extract from celery calico, showing broken line patterns composed of a series of dots or dashes; *C*, margin of leaf showing alternating green and yellow lines from a seedling inoculated with the juice extracted from a delphinium plant naturally infected with calico; *D*, leaf showing green streaks in the chlorotic areas from a seedling inoculated with the extract from Summer Crookneck squash (fruit) naturally infected with calico; *E, F*, leaves from delphinium seedlings inoculated with the expressed juice from celery calico showing ring patterns composed of chlorotic dots encircling green areas or concentric, alternating yellow and green lines surrounding green centers.

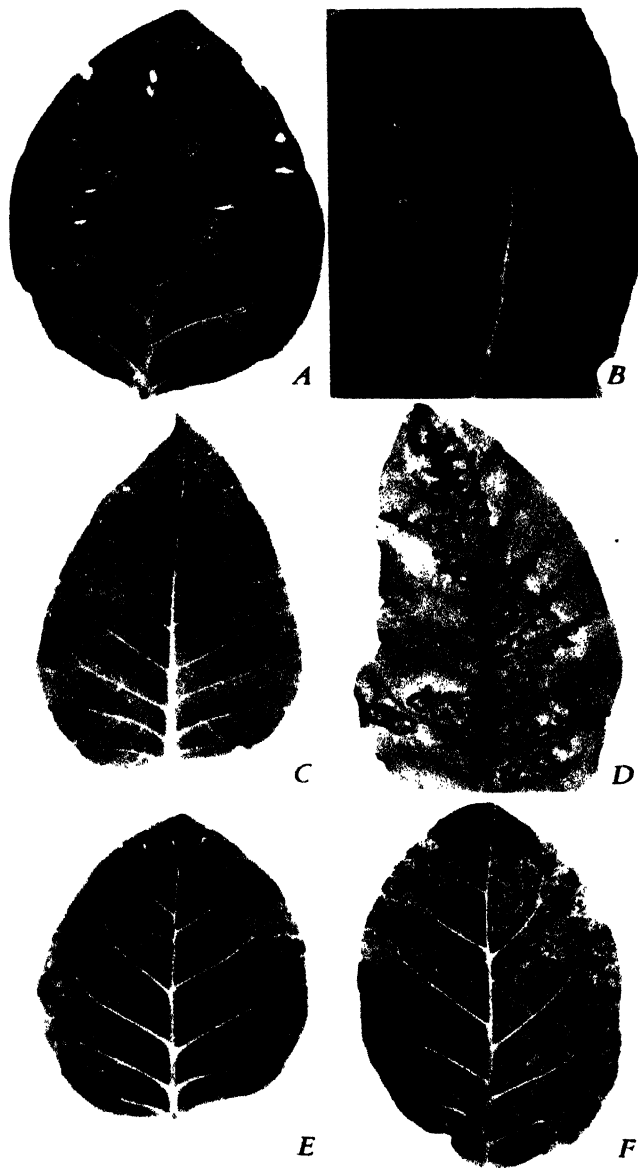


Plate 3.—Leaves from Turkish tobacco (*Nicotiana Tabacum*) and *N. Langsdorffii* infected with the celery-calico-virus extract from celery or from delphinium by mechanical inoculation: A, concentric, necrotic, broken circles—white areas are abrasions caused by inoculation with carborundum; B, portion of Turkish tobacco leaf enlarged showing necrotic dots arranged to form concentric, broken, ring patterns; C, etch or oak-leaf pattern consisting of necrotic dots and lines; D, leaf from *N. Langsdorffii* showing oak-leaf pattern; E, leaf from Turkish tobacco in an advanced stage of the disease showing chlorotic rings encircling green areas and line patterns; F, intervenal, necrotic, etch pattern.

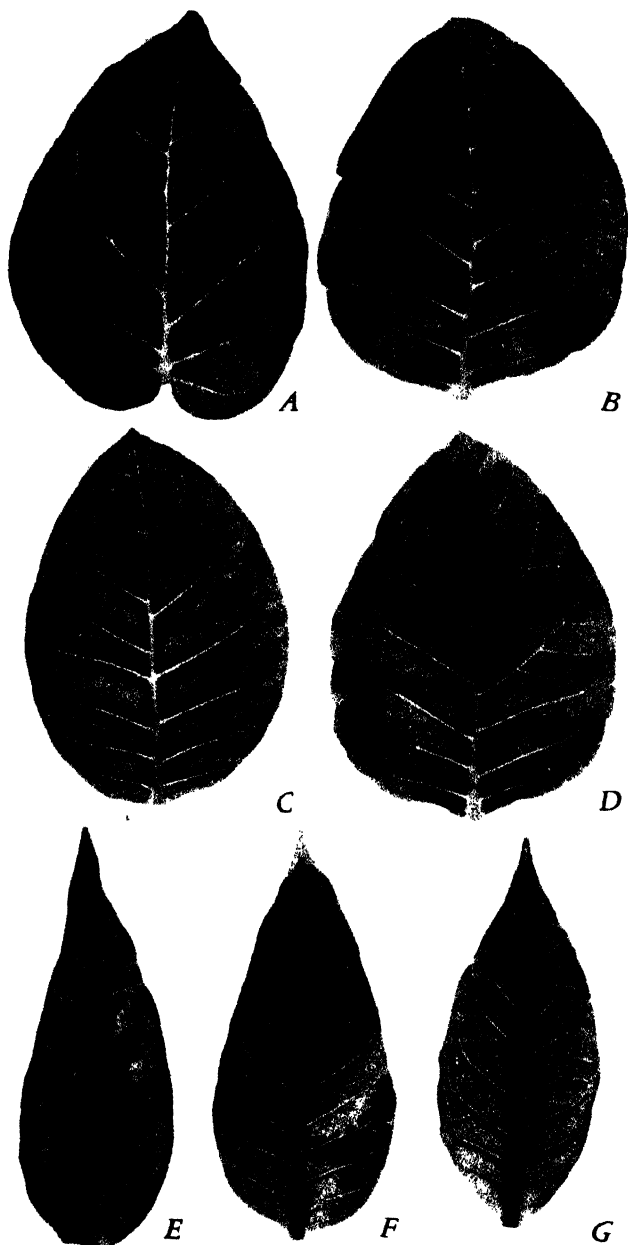


Plate 4.—Leaves from Turkish tobacco (*Nicotiana Tabacum*) infected with the virus of celery calico from delphinium by mechanical inoculation: *A*, intervenal, chlorotic, circular areas which coalesce and form irregular, blotchy mottle, as at *B*, that often extend to the midrib, as at *C*, *D*; *E*, *F*, leaves below flowers showing faint chlorotic areas; *G*, chlorosis extending over almost the entire leaf.

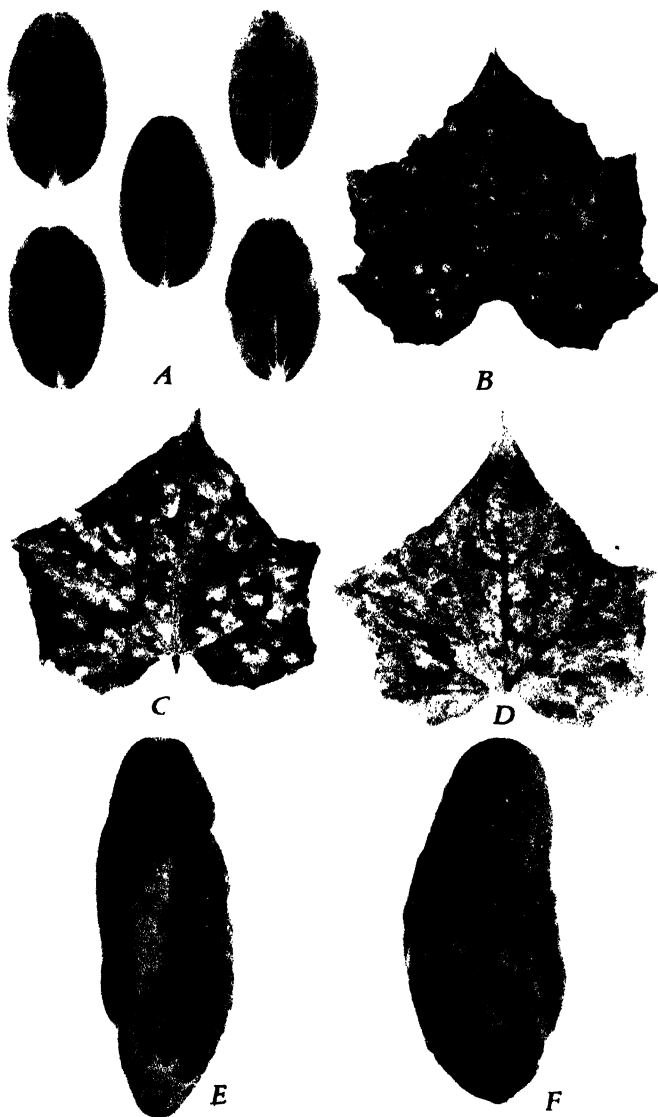


Plate 5.—White Spine cucumber (*Cucumis sativus*) infected with the virus of celery calico from delphinium by mechanical inoculation: A, center, cotyledon from check or control plant and grouped around it four cotyledons showing chlorotic rings enclosing large green areas; B, leaf showing numerous, small, circular, chlorotic spots, which coalesce to form irregular, yellow areas, as at C, that spread over the leaf; D, leaf showing advanced stages of chlorosis with green bands of tissue extending along some of the veins; E, F, cucumber fruits showing irregular, chlorotic mottling.

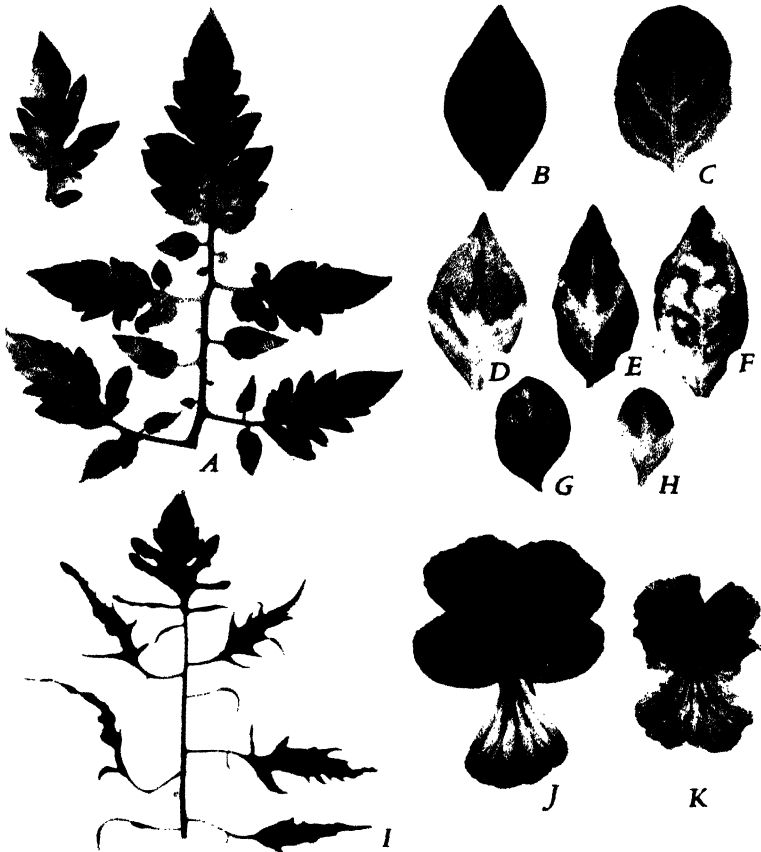


Plate 6.—A, Marglobe tomato (*Lycopersicon esculentum*) experimentally infected with celery calico, leaf and leaflet showing light areas on leaflets which were orange in color. B-H, Rosy Morn petunia (*Petunia hybrida*) infected with the virus of celery calico from delphinium: B, healthy leaf from check or control plant; C, leaf showing cleared venation 6 days after inoculation; D, E, oak-leaf pattern extending along the midrib and lateral veins; F, variable orange and green patterns on a lower or basal leaf; G, orange discoloration along the veins near the tip of a basal leaf; H, orange discoloration near the basal region of a lower leaf and extending along the midrib. I, Fern leaf, filiform leaf, or shoe-string leaf on Marglobe tomato, sometimes produced by tomato mosaic (identical with ordinary tobacco-mosaic virus, tobacco mosaic 1); but the celery-calico virus separated from tobacco mosaic in a virus complex in naturally infected tomato plants rarely induces such symptoms. J-K, *Pupilio viola* (*Viola cornuta*): J, flower from a healthy plant used as a check or control plant; K, breaking in color of flower from a plant inoculated with the virus extract from delphinium naturally infected with celery calico.

PERENNIAL-DELPHINIUM RINGSPOT

HENRY H. P. SEVERIN AND R. C. DICKSON

PERENNIAL-DELPHINIUM RINGSPOT¹

HENRY H. P. SEVERIN² AND R. C. DICKSON³

INTRODUCTION

Among the virus diseases encountered in the course of the investigation of celery calico on perennial delphiniums (5)⁴ was one which caused ringspot of perennial delphinium; this was found on unknown varieties or hybrids at Berkeley, Hillsborough, and Montara, California, the symptoms being identical in the three places. The symptoms of celery calico on delphinium are confined to the basal or intermediate leaves, whereas ringspots occur on all of the leaves.

Work was undertaken on the host range, properties of the virus, and determination of the vectors. The symptoms of the disease were compared with those of ringspot previously reported on delphiniums.

Valleau (7) found a virosis of delphinium in Kentucky closely resembling ringspot of tobacco. He later (8) reported a delphinium virus causing a "coarse etch" when transferred to tobacco and suggested seed transmission. In another paper (9), he described the symptoms in more detail and gave delphinium, tobacco, tomato, and cucumber as host plants of the virus. The symptoms on delphinium consist of chlorotic ring patterns on individual lobes of the affected leaf, sometimes extending into every lobe. He also stated that this disease occurred naturally in tobacco both in Kentucky and in Minnesota and that "this virus corresponds most closely to the typical cucumber viruses."

Johnson (3) found patterns on delphinium similar to the large, yellowish, concentric patterns on dark tobacco caused by a tobacco-ringspot virus identical with that described by Fromme, Wingard, and Priode (2).

Burnett (1) described a virus disease causing dark-brown to black lesions on delphinium leaves. Tobacco plants inoculated from these showed an irregular mottle with ring-and-line patterns. Delphinium plants inoculated from these tobacco plants developed dark-brown ring-and-line patterns during the first season.

MATERIALS AND METHODS

Source of Virus.—The source of ringspot virus used in the work on host range was delphiniums collected at Montara and Berkeley and that of the virus used in the property studies was a single naturally infected

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⁴ Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

delphinium plant obtained in Berkeley. The virus was retained by repeated mechanical inoculation of susceptible host plants.

Virus Extract.—In preparing juice from infected plants, leaves were ground in a sterilized food chopper or in a mortar. The pulp was then placed in two layers of cheesecloth and the juice pressed out by hand.

Mechanical Inoculation.—The carborundum method of mechanical inoculation used was that described by Rawlins and Tompkins (4). Shortly after inoculation the carborundum and inoculum were washed from the leaves with water. The virus extract was usually inoculated into lots of 5 healthy plants. Inoculated plants were observed daily for symptoms. If symptoms failed to develop, tobacco plants were held for 21 days, cucumber plants for 30 days, and plants used in the host-range study for 30 to 60 days or longer, before they were discarded.

Recovery of Virus.—Whether or not symptoms appeared, an attempt was made to recover and transfer the virus from each plant or group of 5 plants used in the host-range studies, to lots of 5 healthy Turkish tobacco or White Spine cucumber plants. The inoculum was taken from young leaves and in some cases from the inoculated leaves also.

Noninfective Insects.—Most of the insects tested to determine the vector of the ringspot virus were from virus-free colonies maintained on caged celery plants in the greenhouse, although a few species of insects were collected in the field. Most of the aphids tested for virus transmission were confined in leaf cages clipped to the leaves of diseased plants and after a feeding period of about 18 hours were shaken from the cages and transferred to healthy seedlings by means of a moist camel's-hair brush. Leafhoppers were captured by means of a 10-cc pipette and were fed on diseased and healthy plants either in leaf cages or in large cages enclosing the plant. Mites were transferred from diseased to healthy plants with a moist camel's-hair brush.

HOST RANGE

The natural host range of delphinium ringspot so far determined is limited to perennial delphiniums. The host range of delphinium ringspot as determined by experimental infection by mechanical inoculation includes 11 species, in 8 genera, in 5 families. Some of the infected host plants developed local lesions, in others the infection was systemic, and one symptomless carrier was demonstrated.

RANUNCULACEAE, CROWFOOT FAMILY

Perennial Delphinium.—The symptoms on the younger leaves of naturally infected perennial delphiniums are faint chlorotic rings, frequently irregular in shape, 1 to 5 mm in diameter, enclosing green (plate

1, A) or yellow centers with concentric chlorotic and green lines (plate 1, A). Small, irregular, chlorotic areas are scattered between the rings (plate 1, A). The mature leaves show irregular chlorotic rings frequently 10 mm in diameter enclosing green areas, yellow bands 1 to 2 mm in diameter, and irregular chlorotic areas 1 to 4 mm wide (plate 1, B). Numerous small, concentric, chlorotic rings occur near the margin and in the serrations of the mature leaves (plate 1, B). The older leaves show large circular or irregular chlorotic areas surrounded by green and yellow lines (plate 1, C, D). Numerous faint chlorotic rings enclosing green centers or masses of small, yellow, circular areas cover more than half of the leaf surface (plate 1, C). The first symptoms on the inoculated leaves of Blackmore and Langdon delphinium are pale-green areas, which soon develop into zonate, pale-yellow ringspots 3 to 10 mm in diameter (plate 1, E). The first symptoms appeared 32 to 42 days after inoculation.

The virus was easily recovered from naturally infected delphiniums and transmitted to other susceptible hosts by mechanical inoculation.

Turban and Persian Buttercups.—Turban and Persian buttercups (*Ranunculus asiaticus*) were symptomless carriers of the delphinium-ringspot virus. Systemic infection occurred and the virus was easily recovered.

CHENOPODIACEAE, GOOSEFOOT OR SALTBUSH FAMILY

Sugar Beet.—Dark-brown necrotic rings, 0.5 to 1.0 mm in diameter, surrounded by semichlorotic areas 2.0 to 3.0 mm in diameter, sometimes encircled by a broken necrotic ring (plate 2, A) developed on the inoculated leaves of sugar beet (*Beta vulgaris*) 21 to 35 days after inoculation. Attempts to recover the virus from beets by juice inoculation to Turkish tobacco and White Spine cucumber plants were unsuccessful.

MALVACEAE, MALLOW FAMILY

Acala Cotton.—No symptoms of the disease developed on the inoculated leaves of Acala cotton (*Gossypium hirsutum*), but dark-brown, irregular, necrotic lesions, 5 mm or less in diameter, sometimes with pale centers, appeared on the young leaves 10 to 12 days after inoculation.

The virus was recovered from this host and transmitted to tobacco and cucumber plants.

SOLANACEAE, NIGHTSHADE FAMILY

Tobacco.—The symptoms of delphinium ringspot on Turkish tobacco (*Nicotiana Tabacum*) consist of zonate, necrotic lesions. The first symptoms to appear on the inoculated leaves 3 to 8 days after inoculation are

brown, shining, sunken, necrotic spots, circular or sometimes irregular in shape and 0.3 to 1.0 mm in diameter (plate 3, *A*). The lesions slowly enlarge during the next day or two (plate 3, *B*), and some of them become surrounded by pale-green halos. Narrow, broken, necrotic rings 3 to 4 mm in diameter appear around each spot 6 to 11 days after inoculation. These broken rings become entire within 1 day and form a green ring about 1 mm wide and the included tissue becomes necrotic (plate 3, *B*). The rings enlarge and become necrotic (plate 3, *C*). When the original spots are less than 2 mm apart, the rings coalesce (plate 3, *D*). A few necrotic rings about 3 mm in diameter may appear in previously normal areas of the leaf. The area surrounded by each ring becomes necrotic within 2 days and may enlarge to become slightly irregular in outline and have a diameter of 6 mm.

The recovery of the virus from inoculated Turkish tobacco plants was possible only while the lesions were still developing. Lesions and small rings of tissue surrounding them were cut from Turkish tobacco leaves 5 days after inoculation; the juice was extracted and inoculated into healthy Turkish tobacco. A few infections were obtained in this manner. The lesions were fully developed 10 days after inoculation, and all attempts to recover the virus from them or from other parts of the plant were unsuccessful. Repeated attempts to recover the virus from inoculated Turkish tobacco plants during a period of 5½ months after their inoculation were failures.

It appears that the virus spreads but a short distance from the point of entrance in this plant, and is rendered inactive by the dying and drying of the tissue that it has invaded.

The symptoms of the disease on White Burley tobacco (*Nicotiana Tabacum*) are similar to those described on Turkish tobacco, and the incubation period is the same, but the necrotic rings are somewhat larger. Attempts to recover the virus from this host plant were unsuccessful.

Nicotiana Glutinosa.—In the early stage of the disease, faint, chlorotic rings enclosing green areas (plate 3, *E*) appear on the inoculated leaves of *Nicotiana glutinosa*; later the peripheries of the rings become necrotic (plate 3, *E*). In the late stage of the disease, concentric rings appeared, followed by complete necrosis within the rings (plate 3, *F*). The lesions become dry and brittle and sometimes are broken and fall out. The incubation period of the disease varied from 15 to 18 days. No systemic infection occurred, and attempts to recover the virus were unsuccessful.

Jasmine Tobacco.—Symptoms on the inoculated leaves of jasmine tobacco (*Nicotiana alata* var. *grandiflora*) are similar to those described for Turkish tobacco. In addition, many of the inoculated leaves develop

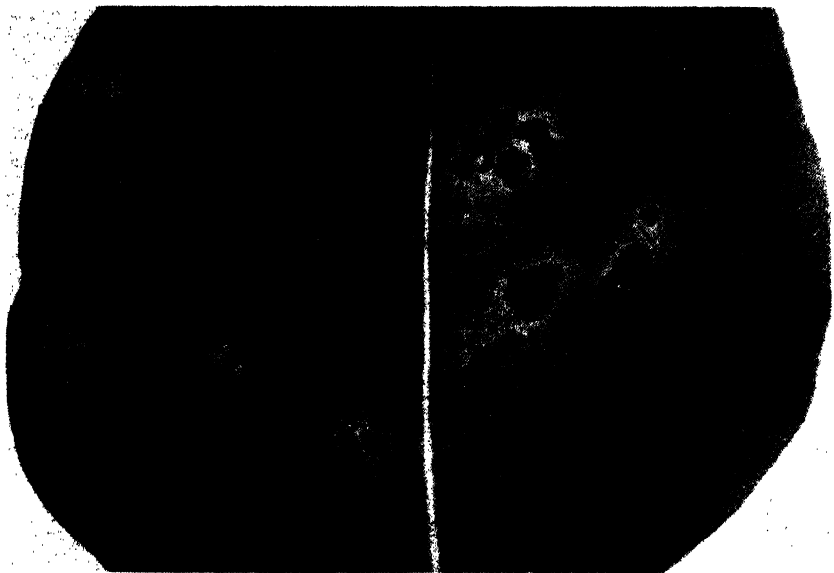


Fig. 1.—*Nicotiana glauca* var. *grandiflora*: leaf 40 days after inoculation with delphinium-ringspot virus, showing groups of dark-brown, necrotic lesions and large zonate ringspots.

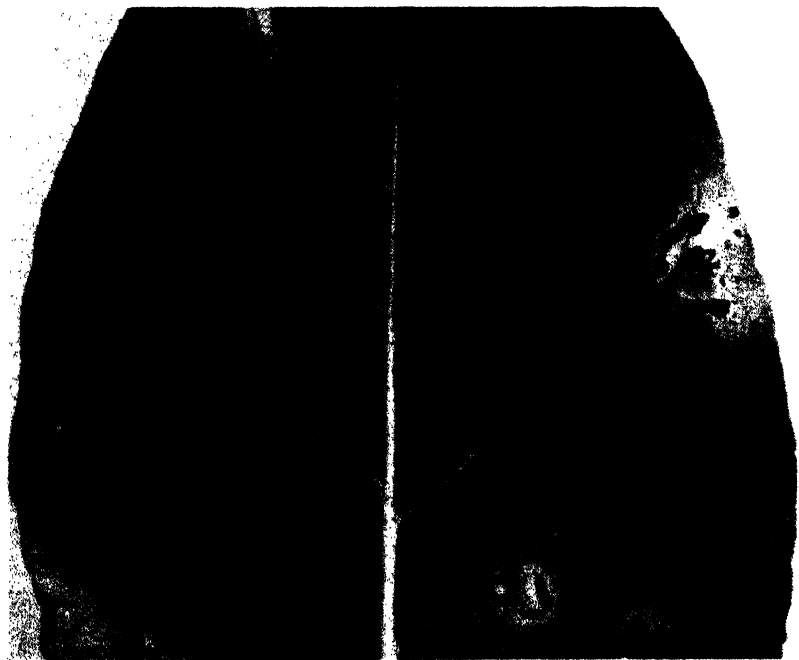


Fig. 2.—*Nicotiana glauca* var. *grandiflora*: leaf which developed after inoculation, showing necrotic ringspots surrounded by broken, necrotic rings 40 days after the plant was inoculated with delphinium-ringspot virus.

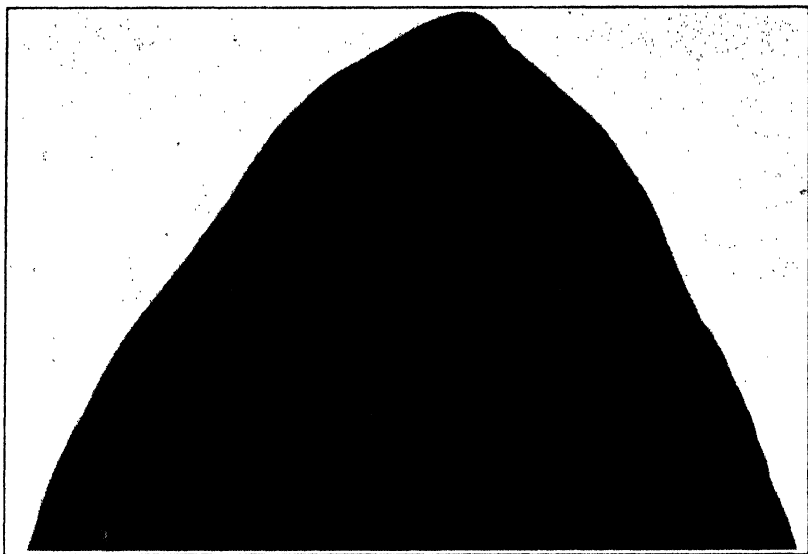


Fig. 3.—Peasant's tobacco (*Nicotiana rustica* var. *humilis*): leaf 9 days after inoculation with delphinium-ringspot virus, showing necrotic rings surrounding necrotic areas.

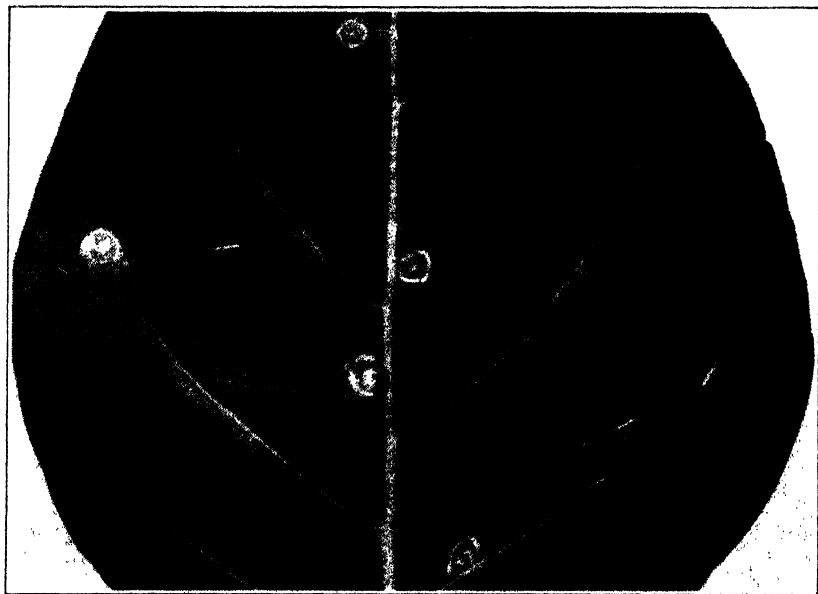


Fig. 4.—Peasant's tobacco (*Nicotiana rustica* var. *humilis*): leaf 11 days after inoculation with delphinium-ringspot virus, showing small target pattern with necrotic center surrounded by alternating green and necrotic rings.

semichlorotic areas surrounding the necrotic lesions. The infection becomes systemic in this host plant, and leaves appearing after inoculation may develop dark-brown, zonate, necrotic lesions (fig. 1) 30 to 60 days after the plant is inoculated. These spots may be surrounded by partial rings of necrotic tissue (fig. 2). Attempts to recover the virus from this host and transmit it to Turkish tobacco and cucumber were unsuccessful.

Peasant's Tobacco.—The early symptoms of the disease on peasant's tobacco (*Nicotiana rustica* var. *humilis*) are similar to those described on Turkish tobacco. Each necrotic lesion or minute ring becomes surrounded by a necrotic ring which also encloses a ring of green tissue (fig. 3). The ringspot may show a small, target pattern with necrotic center surrounded by alternating green and necrotic rings (fig. 4). Later, the entire area within each ring becomes necrotic.

The incubation period of the disease is 5 to 7 days. No recovery was made.

Petunia.—The early symptoms of ringspot on the leaves of Crimson King petunia (*Petunia hybrida*) 5 to 8 days after inoculation are dark-brown, necrotic lesions 1 mm or less in diameter. These enlarge to attain a diameter of 10 mm 2 weeks after inoculation (plate 4, *A, B, C*). Ten to 14 days after inoculation, necrotic lesions (plate 4, *D*), or necrotic spots (plate 4, *E*) or streaks, sometimes along the veins and midrib (plate 4, *F, G*), or rings appear on the young leaves. These symptoms increase in severity so that 30 days after inoculation the leaves are marked by small necrotic lesions or rings (plate 4, *H*), or necrotic concentric rings (plate 4, *I*), or chlorotic rings enclosing brown, dead tissue, or concentric rings (plate 4, *J*), or irregular masses or bands of necrotic tissue (plate 4, *K, L*).

The virus was easily recovered from infected petunia plants and transferred to healthy Turkish tobacco and cucumber plants.

Jimsonweed.—The symptoms on jimsonweed (*Datura Stramonium*) are necrotic, local lesions (plate 2, *B*) similar to those described on Turkish tobacco, but slightly smaller. The development sequence and incubation period are the same. Inoculated leaves which develop many lesions may absciss prematurely. No systemic infection occurs.

CUCURBITACEAE, GOURD FAMILY

Cucumber.—In White Spine cucumber (*Cucumis sativus*), the first symptoms of ringspot which develop on the inoculated cotyledons and true leaves of seedlings, 5 to 10 days after inoculation, are pale-green, circular areas with indistinct margins and each with a white pin-point center, probably marking the point of entrance of the virus. The circu-

TABLE 1
PLANTS UNSUSCEPTIBLE TO DELPHINIUM-RINGSPOT VIRUS

Family and common name	Scientific name	Plants inoculated number
Chenopodiaceae, goosefoot or saltbush family:		
Virginia Savoy spinach.....	<i>Spinacia oleracea</i> L.....	5
Ranunculaceae, buttercup family:		
Annual larkspur.....	<i>Delphinium Ajacis</i> L.....	5
Cardinal larkspur.....	<i>Delphinium cardinale</i> Hook.....	5
Love-in-a-mist.....	<i>Nigella damascena</i> L.....	5
Summer Adonis.....	<i>Adonis aestivalis</i> L.....	5
California buttercup.....	<i>Ranunculus californicus</i> Benth.....	15
Poppy anemone.....	<i>Anemone coronaria</i> L.....	5
Cruciferae, mustard family:		
February cauliflower.....	<i>Brassica oleracea</i> L. var. <i>botrytis</i> L.....	5
Annual stock.....	<i>Mathiola incana</i> R. Br. var. <i>annua</i> Voss.....	3
Violaceae, violet family:		
King of the Black pansy.....	<i>Viola tricolor</i> L. var. <i>hortensis</i> DC.....	5
Tropaeolaceae, Tropaeolum family:		
Golden Gleam nasturtium.....	<i>Tropaeolum majus</i> L.....	10
Leguminosae, pea family:		
Brabham cowpea.....	<i>Vigna sinensis</i> Endl.....	5
Blackeye cowpea.....	<i>Vigna sinensis</i> Endl.....	15
Chilean alfalfa.....	<i>Medicago sativa</i> L.....	5
Horse bean.....	<i>Vicia faba</i> L.....	5
A. & M. Wonder garden pea.....	<i>Pisum sativum</i> L.....	5
Lupine.....	<i>Lupinus polyphyllus</i> Lindl.....	5
Cucurbitaceae, gourd family:		
Cantaloupe.....	<i>Cucumis Melo</i> L. var. <i>cantalupensis</i> Naudin.....	10
Sugar pumpkin.....	<i>Cucurbita Pepo</i> L.....	5
Zucchini squash.....	<i>Cucurbita Pepo</i> L.....	10
White Bush Scallop squash.....	<i>Cucurbita Pepo</i> L.....	5
Umbelliferae, parsley family:		
Golden Self-blanching celery.....	<i>Apium graveolens</i> L. var. <i>dulce</i> DC.....	15
Blue laceflower.....	<i>Trachymene caerulea</i> R. Graham.....	5
Labiatae, mint family:		
Scarlet sage.....	<i>Salvia splendens</i> Ker.....	3
Solanaceae, nightshade family:		
Seedling potato.....	<i>Solanum tuberosum</i> L.....	2
Black Beauty eggplant.....	<i>Solanum Melongena</i> L.....	11
Marglobe tomato.....	<i>Lycopersicon esculentum</i> Mill.....	58
California Wonder bell pepper.....	<i>Capsicum frutescens</i> L.....	5
Scrophulariaceae, figwort family:		
Snapdragon.....	<i>Antirrhinum majus</i> L.....	5
Compositae, sunflower family:		
Large Russian sunflower.....	<i>Helianthus annuus</i> L.....	5
China aster.....	<i>Callistephus chinensis</i> Nees.....	7
Romaine lettuce.....	<i>Lactuca sativa</i> L. var. <i>longifolia</i> Lam.....	8

lar areas become bright yellow in color and vary from 4 to 6 mm in diameter (plate 2, C). An indistinct chlorotic area may later extend from each of the circular spots to adjacent parts of the leaf, sometimes followed by necrosis. After the infection becomes systemic, 9 to 18 days after inoculation, numerous chlorotic rings enclosing green centers or

necrotic spots and chlorotic circular areas appear on the leaves (plate 2, *D*).

The interspaces between the veinlets are sometimes filled by small chlorotic areas (plate 2, *E*), and these may coalesce, especially along the margin of the leaf (plate 2, *F*). Frequently the leaves become chlorotic

TABLE 2
THERMAL INACTIVATION OF DELPHINIUM-RINGSPOV VIRUS

Plants inoculated, source of virus, and no. of source plant	Plants infected of 5 inoculated							
	Unheated control	45° C	50° C	55° C	60° C	65° C	70° C	75° C
	number	number	number	number	number	number	number	number
From delphinium into Turkish tobacco:								
1.....	5	5	5	1	1	0	0	0
2.....	5	5	3	0	0	0	0	0
From cucumber into Turkish tobacco:								
3.....	5	5	3	2	0	0	0	0
4.....	5	5	5	0	0	0	0	0
5.....	5	3	1	0	0	0	0	0
6.....	5	5	5	0	0	0	0	0
7.....	5	5	1	0	0	0	0	0
8.....	2	2	4	0	0	0	0	0
From cucumber into cucumber:								
6.....	5	5	4	0	0	0	0	0
7.....	5	5	4	0	0	0	0	0
8.....	2	5	4	1	0	0	0	0
Total, all sources.....	40	50	39	4	1	0	0	0
Percentages.....	89.1	90.9	70.9	7.3	1.8	0.0	0.0	0.0

with green vein-banding (plate 2, *F*), or may become almost entirely chlorotic; they are usually recurved. The plants become brittle and stunted and are often killed under greenhouse conditions.

This virus is easily recovered from cucumber plants and transmitted to Turkish tobacco and cucumber plants by juice inoculation.

PLANTS UNSUSCEPTIBLE

No infection was obtained by mechanical inoculation in 28 species of plants representing 26 genera in 12 families as shown in table 1. Attempts were made to recover the virus from each lot of 5 plants.

PROPERTIES OF VIRUS

Thermal Inactivation.—The thermal inactivation of the virus was determined with undiluted, extracted juices from the leaves of a naturally infected delphinium plant and also from the leaves and stems of

TABLE 3
TOLERANCE TO AGING IN VITRO OF DELPHINIUM-RINGSPOT VIRUS AT ROOM TEMPERATURE

Plants inoculated, source of virus, and no. of source plant	Plants infected of 5 inoculated after various periods of aging															
	Control number	4 hours number	8 hours number	12 hours number	18 hours number	1 day number	1½ days number	2 days number	3 days number	4 days number	5 days number	6 days number	7 days number	8 days number	9 days number	10 days number
From delphinium into Turkish tobacco:																
1.....	5	5	5	5	2	0	0	0	0	0	0	0	0	0	0	0
2.....	5	5	5	3	4	4	5	5	3	1	0	0	0	0	0	0
3.....	5	5	5	5	2	4	2	4	2	0	0	0	0	0	0	0
4.....	5	5	5	5	3	4	4	0	0	0	0	0	0	0	0	0
5.....	4	3	4	1	1	3	1	0	0	0	0	0	0	0	0	0
6.....	4	2	4	1	4	3	2	0	0	0	0	0	0	0	0	0
7.....	5	5	5	5	5	2	0	0	0	0	0	0	0	0	0	0
From cucumber into cucumber:																
2.....	4	3	5	3	3	3	5	2	3	1	0	0	0	0	0	0
3.....	4	3	1	2	0	1	3	3	2	0	0	0	0	0	0	0
4.....	1	4	3	4	4	5	2	0	1	2	0	0	0	0	0	0
Total, all sources.....	42	40	42	34	28	29	24	14	11	4	0	0	0	0	0	0
Percentage.....	84.0	80.0	84.0	68.0	66.0	58.0	48.0	28.0	22.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 4
TOLERANCE TO DILUTION OF DELPHINIUM-RINGSPOT VIRUS

Plants inoculated, source of virus, and no. of source plant	Plants infected of 5 inoculated, after various dilutions									
	Undiluted control	1:10	1:100	1:500	1:1,000	1:2,000	1:5,000	1:10,000	1:50,000	1:100,000
	number	number	number	number	number	number	number	number	number	number
From delphinium into Turkish Tobacco:										
1.....	5	5	5	5	2	0	0	0	0	0
2.....	5	5	5	3	1	0	0	0	0	0
3.....	5	5	3	2	0	0	0	0	0	0
4.....	4	5	3	2	0	0	0	0	0	0
From cucumber into Turkish tobacco:										
5.....	5	5	3	1	1	0	0	0	0	0
6.....	5	5	4	1	0	0	0	0	0	0
7.....	5	5	2	0	0	0	0	0	0	0
8.....	5	4	2	0	0	0	0	0	0	0
9.....	5	2	1	0	0	0	0	0	0	0
10.....	4	5	2	0	0	0	0	0	0	0
From cucumber into cucumber:										
5.....	5	5	3	0	0	0	0	0	0	0
6.....	5	5	4	1	0	0	0	0	0	0
10.....	4	5	0	2	0	0	0	0	0	0
Total	62	61	37	17	4	0	0	0	0	0
Percentage.....	96.4	98.8	56.9	29.1	6.2	0.0	0.0	0.0	0.0	0.0

experimentally infected cucumber plants. Ten cc of juice from diseased plants was placed in each sterile, thin-walled, test tube by means of a pipette to avoid contamination of the lip of the tube. Each test tube containing the virus extract was immersed in the water bath at the desired temperature for 11 minutes, about 1 minute being required for the heat to penetrate the glass of the test tube. The bath was maintained within 0.5 degree of the desired temperature throughout each test. The water was kept in circulation by an agitator connected to an electric motor. After exposure to the desired temperature, the test tubes were cooled rapidly in running water. After cooling, the juice was poured into a small culture dish and the plants were inoculated without delay. Unheated controls were used in each test. The results obtained are indicated in table 2. The delphinium-ringspot virus was active after heating the expressed juice from delphinium and cucumber plants at 45°, 50°, and 55° C. A single infection was obtained after heating the virus extract from delphinium at 60°. The virus was inactivated by heating to 65°.

Tolerance to Aging in Vitro.—To determine the resistance of the ringspot virus to aging in vitro, test tubes each containing 10 cc of expressed juice from diseased delphinium or cucumber plants were plugged with cotton and kept in the dark at room temperature. Fresh-extract controls were used in each trial. The juice was tested for infectivity by mechanical inoculation after periods of 4, 8, 12, and 18 hours, 1 day, 1½ days, and then daily until 10 days had elapsed. The results are shown in table 3.

It is evident that the virus was active in the cucumber extract in vitro for various periods up to and including 4 days, but was inactivated after 5 days. One virus extraction from delphinium resulted in 2 infections after 18 hours' aging in vitro, but none after 1 day.

Tolerance to Dilution.—The tolerance to dilution of the ringspot virus was determined by diluting the expressed juice from diseased delphinium and cucumber plants with distilled water. The higher dilutions were inoculated first to minimize the danger of accidental infection. Undiluted controls were used in each test. Table 4 indicates the results obtained.

Infections were occasionally obtained at a dilution of 1:1,000 with the extract from delphinium and cucumber plants but not at 1:2,000 or at higher dilutions.

ATTEMPTS TO DETERMINE THE VECTOR

A limited number of insects and mites occur on delphinium under natural conditions in California. The mountain leafhopper (*Thamnotettix montanus* Van D.), the geminate leafhopper (*Thamnotettix gemi-*

TABLE 5
INSECTS AND MITE THAT FAILED TO TRANSMIT RINGSPOT VIRUS

Common and scientific name of insects and mite	Insect or mite			Plants used
	Average number on each plant	Period on diseased plant	Period on healthy plant	

From diseased to healthy delphinium				
	number	days	days	number
Aster leafhopper, <i>Macrostelus divinus</i> (Uhl.)	15	12 hours	3	10
Geminate leafhopper, <i>Thamnotettix geminatus</i> Van D.	24	5 days	24	10
Mountain leafhopper, <i>Thamnotettix montanus</i> Van D.	22	6 days	17	10
Celery leaf aphid, <i>Aphis apigraveolens</i> Essig	27	18 hours	2	10
Celery aphid, <i>Aphis apii</i> Theob.	33	18 hours	2	10
Cotton, or melon, aphid, <i>Aphis gossypii</i> Glover	23	18 hours	4	10
Erigeron root aphid, <i>Aphis middletonii</i> Thomas	29	18 hours	4	10
Cabbage aphid, <i>Brevicoryne brassicae</i> (Linn.)	30	18 hours	3	10
Yellow willow aphid, <i>Cavariella capreae</i> (Fabr.)	23	18 hours	2	10
Turnip, or false cabbage, aphid, <i>Lipaphis pseudobrassicae</i> (Davis)	29	18 hours	2	10
Onion aphid, <i>Micromyzus formosanus</i> Taka	31	18 hours	3	10
Lily aphid, <i>Myzus circumflexus</i> Buckton	28	18 hours	6	10
Foxglove aphid, <i>Myzus consolvuli</i> (Kalt.)	30	18 hours	8	10
Green peach aphid, <i>Myzus persicae</i> (Sulz.)	25	18 hours	7	25
Honeysuckle aphid, <i>Rhopalosiphum melliferum</i> (Hottes)	28	18 hours	3	10
Rusty-banded aphid, <i>Aphis ferruginea-striata</i> Essig	29	18 hours	2	10
Two-spotted mite, <i>Tetranychus bimaculatus</i> Harvey	25	Reared	7	10

From diseased to healthy cucumber plants				
	number	days	days	number
<i>Agallia californica</i> (Baker)	7	2	5	1
Blue-green sharpshooter, <i>Cicadella circellata</i> (Baker)	12	2	5	2
Western potato leafhopper, <i>Empoasca abrupta</i> De L.	5	2	5	2
Cotton or melon aphid, <i>Aphis gossypii</i> Glover	23	2-5	2	20
Erigeron root aphid, <i>Aphis middletonii</i> Thomas	20	2	2	10
Cabbage aphid, <i>Brevicoryne brassicae</i> (Linn.)	15	4	2	1
Turnip, or false cabbage, aphid, <i>Lipaphis pseudobrassicae</i> (Davis)	15	4	2	5
Onion aphid, <i>Micromyzus formosanus</i> Taka	8	4	2	2
Lily aphid, <i>Myzus circumflexus</i> Buckton	24	2	2	22
Green peach aphid, <i>Myzus persicae</i> (Sulz.)	24	2	3	20
Rusty-banded aphid, <i>Aphis ferruginea-striata</i> Essig	20	2	2	10
Two-spotted mite, <i>Tetranychus bimaculatus</i> Harvey	22	Reared	4	10

From diseased to healthy turban and Persian buttercup plants				
	number		days	number
Ornate aphid, <i>Myzus ornatus</i> Laing	17	Reared	10	15
Cyclamen mite, <i>Tersonemus pallidus</i> Banks	10	Reared	30	10

natus Van D.) and two species of mites—the two-spotted mite (*Tetranychus bimaculatus* Harvey), and the cyclamen mite (*Tarsonemus pallidus* Banks)—were found breeding on delphinium. An occasional green peach aphid (*Myzus persicae* [Sulz.]) and undetermined dead winged aphids were found on this plant under natural conditions. The insects and the mite which failed to transmit the ringspot virus from diseased to healthy delphinium are listed in table 5.

Since the virus is easily transmitted to various host plants by mechanical inoculation, it was assumed that the vector is probably an aphid. Tests were made with colonies of various species of aphids maintained in the greenhouse. Insects which could not be reared on delphinium were fed on diseased plants for periods of from 12 to 18 hours and then were transferred to healthy delphinium seedlings.

Daily observations were made on the mortality of the insects, and after the last insect of a lot was dead (table 5), the seedlings were fumigated. The last living specimen of an average lot of 30 foxglove aphids (*Myzus convolvuli* [Kalt.]) survived on seedling delphinium for 8 days, green peach aphid, (*M. persicae* [Sulz.]) for 7 days, lily aphid (*M. circumflexus* Buckton) for 6 days, and all other species of aphids for 2 to 4 days, as shown in table 5.

No transmission of the virus was obtained with any of the various species of aphids tested.

Unsuccessful attempts were made to transmit the virus by means of leafhoppers, aphids, and mites from White Spine cucumbers infected with the ringspot virus to healthy cucumber plants. A list of insects and mites that failed to transmit the ringspot virus from diseased to healthy cucumber plants is given in table 5.

Transmission of the virus from diseased to healthy turban and Persian buttercups (*Ranunculus asiaticus*) was attempted, with aphids and mites but was unsuccessful. A list of the aphids and mites which failed to transmit the virus is shown in table 5.

DISCUSSION

Valleau (9) lists delphinium, Turkish tobacco, tomato, and cucumber as hosts of a virus found in delphinium in Kentucky. Tomato plants could not be infected with the California delphinium-ringspot virus. A total of 58 Marglobe tomato plants were inoculated, but no symptoms developed, and all attempts to recover the virus from these plants were failures.

The symptoms described by Valleau (9) on delphinium and Turkish tobacco as produced by the virosis on delphinium in Kentucky are not identical with the symptoms produced on the same host plants by the

ringspot virus in California. It is therefore evident that the two viruses are not identical.

The symptoms of tobacco ringspot on delphinium described by Johnson (3) differed from those produced on this host plant by the delphinium-ringspot virus in California. The symptoms of tobacco ringspot on delphinium and cucumber are described in another paper of this series (6).

The symptoms described by Burnett (1) on delphinium and tobacco also differed from those produced on these host plants by the delphinium-ringspot virus in California.

DESCRIPTION OF DELPHINIUM-RINGSPOT VIRUS

Name: Delphinium ringspot.

Host families: Ranunculaceae, Chenopodiaceae, Malvaceae, Solanaceae, and Cucurbitaceae.

Symptoms of disease: On young leaves of delphinium faint chlorotic rings enclosing green or yellow centers; on mature leaves, irregular chlorotic rings encircling green areas, yellow bands, and irregular chlorotic areas.

Incubation period of disease: 32 to 42 days in the greenhouse.

Property studies: Thermal inactivation 65° C in 10 minutes' exposure, tolerance to dilution 1:1,000, and resistance to aging in vitro 5 days.

Modes of transmission: Mechanical inoculation with expressed juice, in nature vector was not found.

SUMMARY

Perennial or garden delphinium was demonstrated to be naturally infected with an undescribed ringspot virus.

The host range of the ringspot virus as determined by mechanical inoculation includes 11 species of plants in 8 genera belonging to 5 families, as follows:

Ranunculaceae, crowfoot family:

Blackmore and Langdon perennial delphinium (*Delphinium* sp.), systemic infection, virus recovered.

Turban and Persian buttercups (*Ranunculus asiaticus*), symptomless carrier, virus recovered.

Chenopodiaceae, goosefoot or saltbush family:

Sugar beet (*Beta vulgaris*), local infection, virus not recovered.

Malvaceae, mallow family:

Acala cotton (*Gossypium hirsutum*), systemic infection, virus recovered.

Solanaceae, nightshade family:

Turkish tobacco (*Nicotiana Tabacum*), local infection, virus recovered only while the lesions were developing.

White Burley tobacco (*Nicotiana Tabacum*), local infection, virus not recovered.

Nicotiana glutinosa, local infection, virus not recovered.

Nicotiana glauca var. *grandiflora*, systemic infection, virus not recovered.

Peasant's tobacco (*N. rustica* var. *humilis*), local infection, virus not recovered.

Crimson King petunia (*Petunia hybrida*), systemic infection, virus recovered.

Jimsonweed (*Datura Stramonium*), local infection, virus not recovered.

Cucurbitaceae, gourd family:

White Spine cucumber (*Cucumis sativus*), systemic infection, virus recovered.

Twenty-eight species of plants in 26 genera in 12 families were inoculated with the ringspot virus but proved unsusceptible.

The thermal inactivation of the ringspot virus was 65° C in a 10-minute exposure. Inactivation of the virus occurred after the extracted juice from diseased cucumber plants was exposed to the air at room temperature for a period of 5 days. The tolerance to dilution of extracted juice from diseased delphinium and cucumber plants was 1:1,000.

All attempts to find a vector of the ringspot virus were failures.

ACKNOWLEDGMENTS

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PLATES

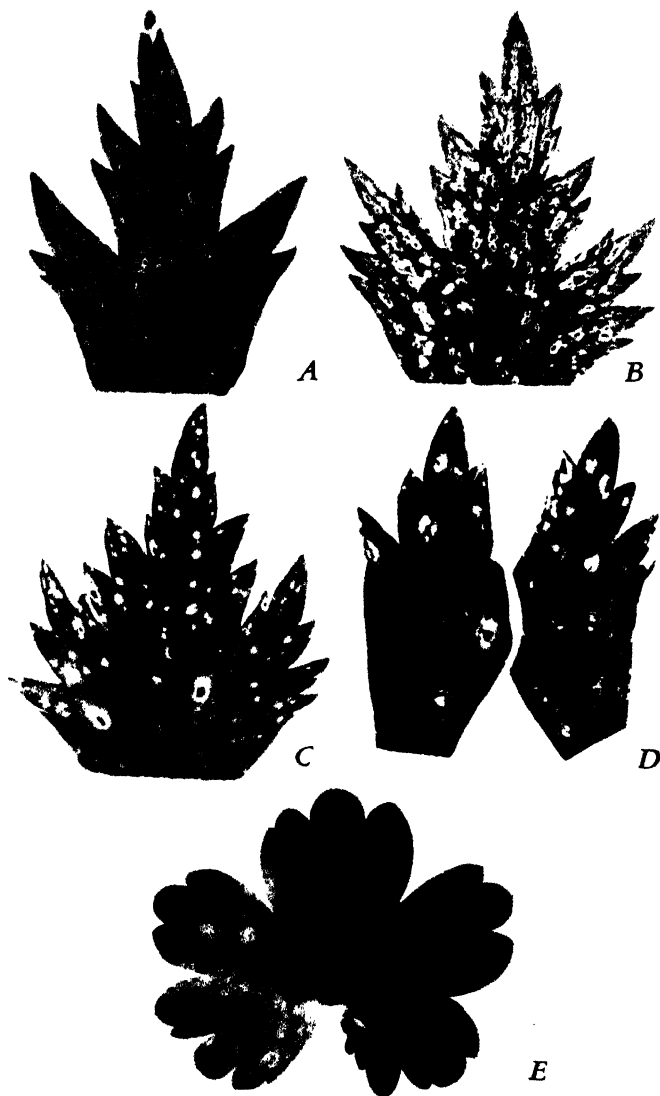


Plate 1.-Perennial delphinium naturally infected with ringspot: *A*, lobe of young leaf showing faint, chlorotic rings enclosing green or yellow centers, and small, irregular, chlorotic areas scattered between the rings; *B*, lobe of mature leaf from the same plant showing irregular, chlorotic rings enclosing green areas, yellow bands, irregular, chlorotic areas, and numerous, small, concentric rings near the margin and in the serrations; *C*, lobe of old leaf from the same plant showing large, circular or irregular, chlorotic areas, each surrounded by a green line, and sometimes with a green center, also masses of small yellow, circular areas, and faint chlorotic rings enclosing green centers; *D*, enlarged lobes of mature leaves from the same plant showing yellow rings enclosing chlorotic or green areas or both; *E*, inoculated leaf from Blackmore and Langdon delphinium showing pale, yellow ringspots with concentric lines.

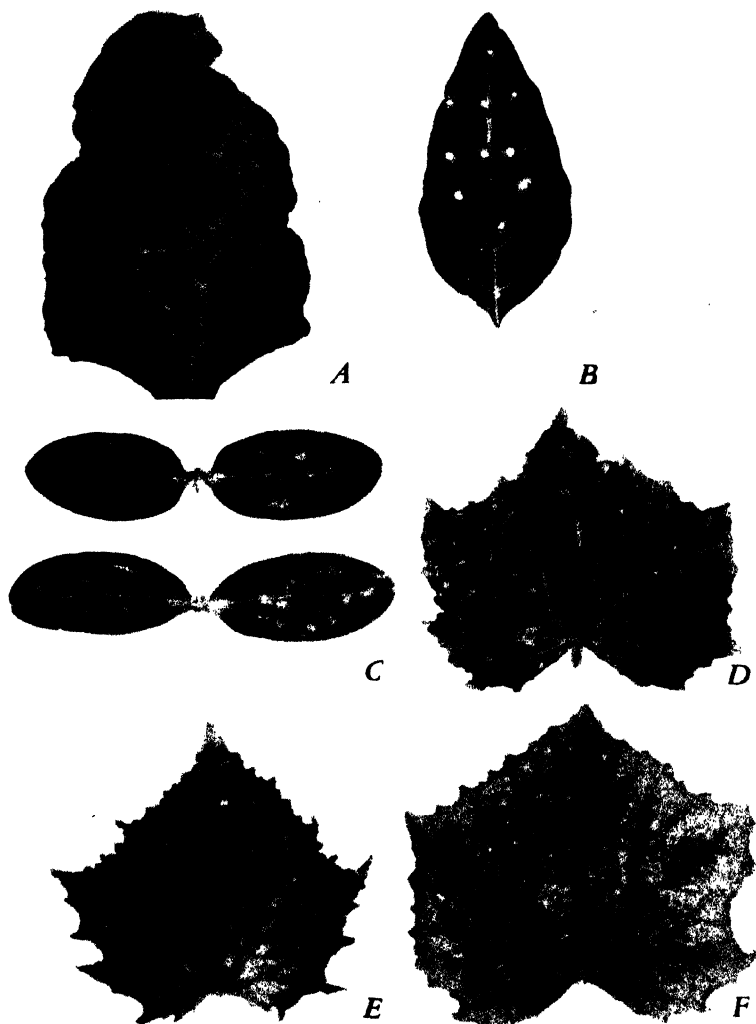


Plate 2.—Symptoms of delphinium ringspot on leaves of various host plants: A, leaf of sugar beet (*Beta vulgaris*) showing necrotic rings surrounded by chlorotic areas 24 days after inoculation; B, leaf of jimsonweed (*Datura Stramonium*) showing concentric rings 13 days after inoculation; C, cotyledons of White Spine cucumber (*Cucumis sativus*) showing circular, yellow areas, each with a white or necrotic pin point in the center, 11 days after inoculation; D, leaf of cucumber plant 26 days after inoculation, showing numerous, chlorotic rings enclosing green centers or necrotic spots; E, leaf of cucumber plant 23 days after inoculation, showing chlorotic areas in the interspaces of the veinlets; F, leaf of cucumber plant showing numerous chlorotic areas which frequently coalesce, and green vein-banding.

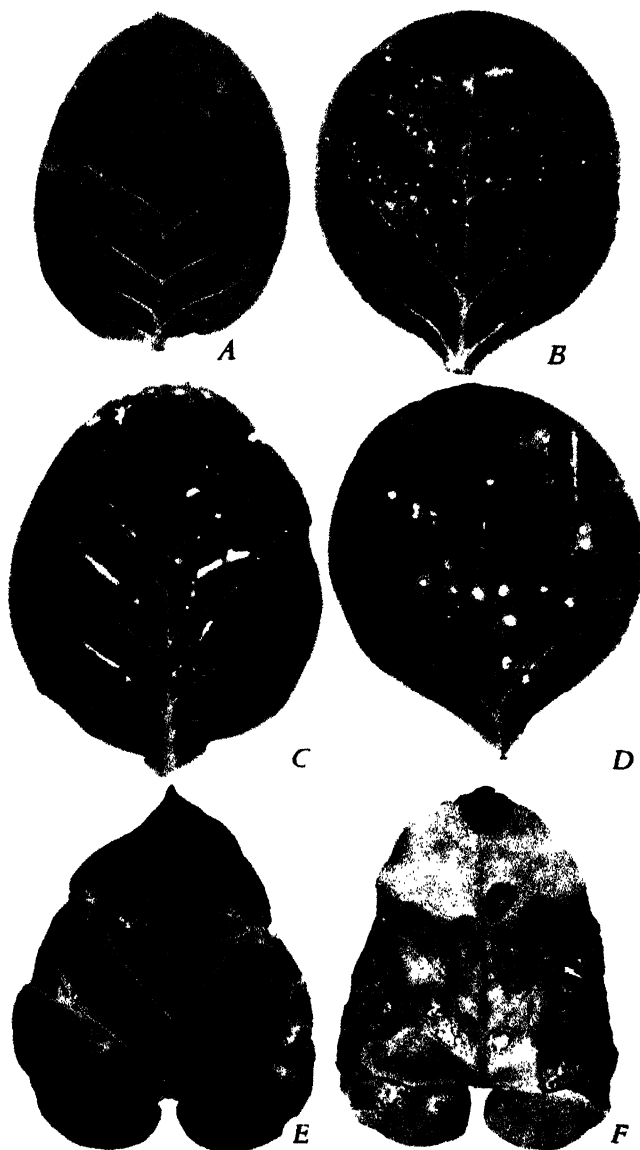


Plate 3.—Symptoms of delphinium ringspot on Turkish tobacco (*Nicotiana glauca*) and *N. glutinosa*: A, leaf showing small, necrotic lesion 4 days after inoculation; B, leaf 6 days after inoculation, showing necrotic areas enlarged and with centers bleached; C, leaf 9 days after inoculation showing necrotic areas surrounded by wider rings—white areas are abrasions caused by inoculation with carborundum; D, leaf 10 days after inoculation, showing ringspots, some of which had coalesced; E, leaf of *N. glutinosa* showing early stage of ring formation with a faint, wide, chlorotic ring enclosing a green area; later, the periphery of the rings becomes necrotic; F, leaf of *N. glutinosa* 4 weeks after inoculation, showing concentric rings and complete necrosis within the rings.



Plate 4.—Crimson King petunia (*Petunia hybrida*) infected with delphinium-ringspot virus: A, B, C, leaves showing large, necrotic lesions 14 days after inoculation; D, necrotic lesions on new leaf; E, F, G, necrotic spots or streaks, sometimes along the veins or midrib on young leaves; H, small, necrotic rings on leaves which developed 30 days after inoculation; I, necrotic, concentric rings; J, chlorotic rings enclosing brown, dead tissue; K, L, irregular masses or bands of necrotic tissue.

THE EFFECT OF CERTAIN ADDED MATERIALS ON BORDEAUX MIXTURE IN THE CONTROL OF PEACH BLIGHT AND LEAF CURL¹

EDWARD E. WILSON²

INTRODUCTION

IN THE STANDARD method for controlling peach blight, caused by *Coryneum Beijerinckii* Oud., bordeaux mixture (10–10–100) is applied to the trees after all leaves are off in the autumn, but before the winter rains begin. Since this is the only application given to protect the twigs against blight during the following three or four months, when heavy and prolonged rains occur, and since this application is also expected to prevent leaf curl caused by *Taphrina deformans*, success of the control is largely dependent upon resistance of the fungicide deposit to dissipation by atmospheric agencies.

In earlier trials (12),³ bordeaux to which 4 per cent of a dormant petroleum-oil emulsion was added, proved more weather-resistant than bordeaux without oil—results that were in agreement with those of Winston, Bowman, and Yothers (14). In 1936–37 and 1937–38, therefore, further trials were undertaken to determine whether smaller amounts of petroleum oil would reduce the loss of bordeaux from peach twigs as effectively as 4 per cent does, and whether other materials such as cottonseed oil and bentonite were useful in this respect.

The effect of petroleum oil on the toxicity of bordeaux to spores of *Coryneum Beijerinckii* (13), and on the spray's "retention"⁴ and "coverage"⁵ qualities were also studied.

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³ Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

⁴ The literature is not unanimous regarding designation of the qualities that determine the efficacy of insecticides and fungicides. Thus the amount of spray per unit of surface remaining after application, is called "initial spray deposit" (16), "deposition" (8), "initial adhesiveness" (9), and "retention" (2); the distribution of the material over the surface is "coverage" (3); and the resistance to weathering is "adherence" (10) or "tenacity" (2). Horsfall, Heuberger, Sharvelle, and Hamilton (8) designate as "fungicidal value" that ability of the material to prevent spore germination; but the present writer prefers "toxicity" or "toxicological value."

EFFECT OF PETROLEUM OIL, COTTONSEED OIL, AND BENTONITE ON TENACITY OF BORDEAUX

Each spray treatment was given in the autumn to four randomized plots, each containing four Paloro peach trees of fairly uniform size. The treatments were bordeaux mixture (10-10-100) to which had been added different amounts of petroleum-oil emulsion, tank-mix petroleum oil, cottonseed oil, or bentonite. Emulsion A was a flowable-type emulsion containing 80 per cent, by weight, of a petroleum oil of 102 seconds Saybolt viscosity and 70 per cent unsulfonated residue. Tank-mix oil was a petroleum oil similar to that in emulsion A emulsified with blood albumin just before it was added to the spray tank. Emulsion B was a paste-type emulsion containing 82 per cent, by weight, of a petroleum oil of 96 seconds viscosity and 94 per cent unsulfonated residue. The cottonseed oil was a commercial grade. The bentonite was a natural product containing some magnesium oxide.

As soon as the spray dried, 200- to 250-gram samples of twigs produced during the past summer were collected and weighed. The twigs were then cut into convenient lengths, placed in glass jars, and shaken for 10 minutes with 500 cc of nitric acid water (20 cc nitric acid, of 1.42 sp. gr., per liter). The wash water was filtered and tested for copper by the sodium diethyl dithiocarbamate method⁵ that Callan and Henderson (1) described.

Other collections were made after several inches of rain had fallen (December or January) and again just before the buds swelled in the spring (February). The amounts of copper on these samples were the basis for determining the weather resistance or tenacity of the bordeaux.

Experiments of 1936-37.—Sprays were applied November 20, 1936, well before the first major wave of twig infection by *Coryneum* which was initiated during rains falling between December 20 and 28. The season was marked by recurrent attacks of the disease during January, February, and March—particularly severe being a wave initiated in early March.

According to the November 20 analyses (table 1), considerable variability existed in the initial amount of copper deposited by the various treatments. These data, together with those secured in other years, will be discussed later.

⁵ In the present work the results obtained by the Callan and Henderson method were consistently higher, by about 3 per cent, than results obtained by the electro-metric method, but compared more favorably with those secured by the iodometric method. Though the last-named method cannot be used when very small amounts of copper are to be determined, it is a valuable referee for standards used in colorimetric tests.

TABLE 1

EFFECT OF PETROLEUM OIL AND BENTONITE ON TENACITY OF BORDEAUX DEPOSIT AND ON CONTROL OF PEACH BLIGHT, 1936-37

Amount and type of material added to bordeaux (10-10-100)*	Deposit November 20, milligrams copper on 100 grams of twigs	Analyses, January 6†		Analyses, February 23‡		Disease, March 11-14§		Disease, April 26-29¶		
		Milligrams copper on 100 grams of twigs	Per cent of copper lost	Milligrams copper on 100 grams of twigs	Per cent of copper lost	Per cent of twigs infected	Average number of lesions on 100 twigs	Per cent of twigs infected	Average number of lesions on 100 twigs	Per cent of twigs killed by the disease
None.....	28.9	10.7	62.0	2.6	90.9	12	15	61	104	14
1 per cent of petroleum emulsion A.....	18.4	6.8	62.9	2.0	88.6	26	30	73	241	26
2 per cent of petroleum emulsion A.....	24.9	12.5	49.4	3.8	84.3	7	9	38	52	7
3 per cent of petroleum emulsion A.....	20.4	13.3	34.6	3.8	81.6	7	9	68	133	13
4 per cent of petroleum emulsion A.....	40.9	29.9	27.3	11.5	71.9	2	2	19	27	4
1 per cent of petroleum emulsion B.....	16.6	5.9	63.9	1.7	89.0	10	12	74	143	18
2 per cent of petroleum emulsion B.....	34.4	20.0	41.7	7.8	77.8	4	4	18	27	3
0.6 pound of bentonite per 100 gallons.....	24.3	10.7	55.7	2.6	88.1	8	11	64	117	10
2 pounds of bentonite per 100 gallons.....	23.6	9.8	53.3	2.2	89.8	11	15	50	87	11
Differences required { 19:1 odds.....	.....	.....	9.58	.....	5.70	4.04	6.03	9.08	33.62	4.83
for significance† 99:1 odds.....	.....	.....	12.95	.....	7.72	5.48	8.17	12.31	45.56	6.54
Calculated F value||.....	.....	.....	15.94	.....	11.17	24.62	15.11	4.90	33.94	18.37

* Bordeaux made with quicklime.

† Analyses made after 2.73 inches of rainfall.

‡ Analyses made after 11.83 inches of rainfall.

§ On March 11-14 in unsprayed trees the percentage of twigs infected was 94, and the average number of lesions per 100 twigs was 387. On April 26-29 these values were 99 and 1,490, respectively, and the percentage of twigs killed was 46.

¶ The differences required for significance at odds of 19:1 and 99:1 were obtained by multiplying the standard error of the difference by t values of 2.145 and 2.977 respectively.|| All these ratios exceed the F value for the 1 per cent point.

After 2.73 inches of rain had fallen, analyses (January 6) revealed marked differences in rate of copper loss from trees receiving the various treatments. Apparently neither of the two types of oil (emulsion A and emulsion B) when used at the rate of 1 per cent influenced the tenacity of bordeaux. The February 23 analyses further emphasize this point, the percentage of copper lost being practically the same for bordeaux alone, bordeaux with 1 per cent of emulsion A, and bordeaux with 1 per cent of emulsion B. Neither in the January 6 nor in the February 23 analyses was bentonite found significantly to reduce the loss of copper.

Increasing the amounts of oil emulsion above the 1 per cent resulted in successively improved tenacity. In this respect, 4 per cent of emulsion A was significantly more efficient than 2 or even 3 per cent, and 2 per cent of emulsion B produced greater tenacity than 1 per cent.

January 6 analyses showed that most treatments still retained considerable amounts of copper. Exceptions were bordeaux plus 1 per cent of emulsion A and bordeaux plus 1 per cent of emulsion B, where the low amount of residue was influenced by low initial deposits. The depletion of the spray coating on trees receiving these two treatments is reflected in the control data obtained March 11-14. Bordeaux plus 1 per cent of emulsion A, in particular, was showing signs of losing its effectiveness at this time. The possibility that the addition of oil might have affected the initial deposit will be discussed later.

According to data on disease conditions in unsprayed trees, as given in the footnote of table 1, most other treatments gave good control up to March 11-14. During early March, however, rains initiated abundant infection; the resulting lesions appeared after March 14, and between this date and April 26-29 the number of lesions on unsprayed trees more than tripled. Bordeaux and bordeaux plus 1 per cent of emulsion A or of B gave poor control during this period, whereas bordeaux plus 2 or 4 per cent of emulsion A and bordeaux plus 2 per cent of emulsion B proved much more efficient. The poor control obtained with bordeaux plus 3 per cent of emulsion A cannot be explained fully by the data at hand. The low initial deposit may have been responsible to some extent, though the amount of copper remaining on February 23 was the same as that for 2 per cent of emulsion A. The 3 per cent of emulsion treatment controlled well up to the early March infection period, but failed thereafter.

Bentonite did not significantly influence the control one way or the other.

On February 1, 1937, bordeaux with and without oil was applied to almond trees. As no blight of consequence developed in this orchard,

TABLE 2
RELATION OF PETROLEUM OIL EMULSION TO THE RETENTION AND TENACITY
OF BORDEAUX DEPOSIT ON ALMOND TWIGS, 1937

Amount of oil added to bordeaux (10-10-100)	Analyses, February 1; milligrams of copper per 100 grams of twigs*	Analyses, February 14; milligrams of copper per 100 grams of twigs†	Per cent of copper lost
None.....	22.1	6.4	71.1
1 per cent of emulsion A.....	24.1	4.7	81.5
3 per cent of emulsion A.....	30.0	16.9	44.7
Difference required for significance:‡			
{ 19:1 odds.....	3.65	3.90	12.7
{ 99:1 odds.....	5.24	5.60	18.3
Calculated <i>F</i> values§.....	12.85	29.43	23.58

* Spray was applied February 1 and samples for these analyses were made immediately after it dried.

† Between February 1 and February 14, 5.19 inches of rain fell.

‡ The differences required for significance at odds of 19:1 and 99:1 were obtained by multiplying the standard error of the difference by *t* values of 2.262 and 3.250 respectively.

§ All these ratios exceed the *F* value for the 1 per cent point.

TABLE 3
EFFECT OF DIFFERENT SUPPLEMENTS ON THE CONTROL OF PEACH LEAF CURL BY
BORDEAUX MIXTURE

Amount and type of material added to bordeaux (10-10-100), 1936-37*	Per cent of leaves diseased†	Amount and type of material added to bordeaux (10-10-100), 1937-38*	Per cent of leaves diseased†
Unsprayed.....	56	Unsprayed.....	49
None.....	2	None.....	0.4
1 per cent of petroleum emulsion A....	8	1 per cent of petroleum emulsion A....	2
2 per cent of petroleum emulsion A....	0.4	3 per cent of petroleum emulsion A....	0.2
3 per cent of petroleum emulsion A....	2	1 per cent of petroleum tank-mix oil...	1
4 per cent of petroleum emulsion A....	0.4	3 per cent of petroleum tank-mix oil...	0.1
1 per cent of petroleum emulsion B....	2	1 per cent of cottonseed oil.....	1
2 per cent of petroleum emulsion B....	0.5		
0.6 pound of bentonite per 100 gallons..	0.7		
2 pounds of bentonite per 100 gallons..	0.5		

* Sprays were applied in 1936-37 on November 20; in 1937-38 on November 23.

† Observations on leaf infection made in late April. The percentage of leaves infected was determined by counting the leaves on 20 randomly selected twigs in each tree.

evidence on control was not obtained. The data on copper analyses (table 2), however, further confirmed the results secured on peaches, in that 1 per cent of oil emulsion had no effect on bordeaux tenacity, whereas 3 per cent materially increased it.

As peach-leaf curl developed abundantly on unsprayed trees, counts were made on the percentage of leaves diseased in trees receiving the treatments listed in table 1. The results (table 3) showed no marked failure of any treatment to control this disease, though in one of the

TABLE 4

EFFECT OF PETROLEUM AND COTTONSEED OILS ON TENACITY OF BORDEAUX DEPOSIT AND ON CONTROL OF PEACH BLIGHT, 1937-38

Amount and type of oil added to bordeaux (10-10-100)*	Deposit November 23, milligrams copper on 100 grams of twigs	Analyses, December 24†		Analyses, February 7‡		Disease development, May 4-5§		
		Milligrams copper on 100 grams of twigs	Per cent of copper lost	Milligrams copper on 100 grams of twigs	Per cent of copper lost	Per cent of twigs infected	Average number of lesions on 100 twigs	Per cent of twigs killed by the disease
None.....	36.0	23.1	35.8	9.6	73.7	76	176	10
1 per cent of petroleum emulsion A.....	23.9	14.5	39.4	7.4	69.3	77	190	13
3 per cent of petroleum emulsion A.....	26.5	21.8	18.8	12.9	49.4	75	153	7
1 per cent of petroleum tank-mix oil.....	31.2	24.0	23.0	7.3	75.9	78	195	13
3 per cent of petroleum tank-mix oil.....	32.1	27.5	13.3	13.7	57.5	69	129	8
1 per cent of cottonseed oil.....	28.7	19.1	33.5	11.2	60.9	70	155	7
Difference required for significance { 19:1 odds.....	.....	.....	12.96	.....	13.30	11.70	62.27	4.84
Calculated F values.....	.....	.....	17.92	.....	19.40	16.18	86.11	6.89
	.....	.....	5.18‡	.....	5.44‡	0.82	1.49	2.33

* Sprayed November 23. Bordeaux made with quicklime.

† Analyses made after 4.4 inches of rainfall.

‡ Infection before spray was applied resulted in 46 per cent of twigs becoming diseased with an average of 146 lesions per 100 twigs. On May 4-5 the percentage of twigs

infected, average number of lesions per 100 twigs, and percentage of twigs killed in unsprayed trees were 96, 1278, and 43, respectively.

§ The differences required for significance at odds of 19:1 and 99:1 were obtained by multiplying the standard error of the difference by t values of 2.131 and 2.947 respectively.

|| Exceeds F value for the 1 per cent point.

four replications of bordeaux plus 1 per cent of emulsion A the incidence of the disease was rather high.

Experiments of 1937-38.—Twig infection was initiated in mid-November, 1937, and in consequence a considerable part of the disease recorded in the final counts on May 4-5, 1938, was present in the trees when the sprays were applied on November 23. The major part of the twig lesions appeared during November and December; none appeared during January, and only a few in February. Therefore, disease development in this season differed markedly from that in 1936-37, when lesions were appearing throughout the winter and a particularly large number appeared in early March. It is apparent that the problem of control in 1937-38 also differed from that in 1936-37, although the incidence of the disease was the same in both years (footnotes to tables 1 and 4).

Sprays were applied on November 23, and samples collected on the same day were analyzed for initial deposits (table 4). Collection of samples on December 24 (after 4.4 inches of rainfall) indicated, as in 1936-37, that 1 per cent of oil emulsion A did not affect bordeaux tenacity; but 3 per cent increased the tenacity considerably. The same general relation between these treatments and bordeaux without oil was maintained up to February 7, during which time an additional 6.35 inches of rain fell. According to the December 24 analyses 1 per cent of tank-mix oil appeared to favor bordeaux tenacity, but the February 7 analyses revealed no advantage over bordeaux without oil. Three per cent of tank-mix oil was about as efficient as 3 per cent of emulsion A in preventing copper loss. One per cent of cottonseed oil appeared, in the February 7 analyses, to have decreased the loss only slightly if any.

As was mentioned at the beginning of this section, twig lesions were developing in the trees at the time the sprays were applied. Two days after application an average of 146 lesions per 100 twigs were present on 46 per cent of the twigs. To show more clearly the control situation, the increment of 146 lesions per 100 twigs is deducted from the results in table 4 and is arranged with the data on copper residues as of February 7 (table 5). Some correlation between the amount of copper remaining on the twig and the number of new lesions is thus shown. The copper residues on this date have the same general relation to the percentage of twigs killed, although such differences cannot be considered statistically significant (table 4).

When, therefore, deductions are made for the disease developing before sprays were applied, all treatments are seen to give excellent control. The reason for this high efficiency is the manner in which disease

developed: the major attacks came early in the winter at a time when the spray film on the trees was new, instead of in late winter after weathering had reduced it, as in 1936-37.

TABLE 5

RELATION OF AMOUNT OF COPPER REMAINING ON TWIGS NEAR THE
END OF THE SEASON TO THE CONTROL OF PEACH BLIGHT OBTAINED
WITH BORDEAUX AND BORDEAUX PLUS OIL, 1937-38

Amount and type of material added to bordeaux (10-10-100)*	Milligrams of copper per 100 grams of twigs, February 7	Average number of lesions (per 100 twigs) developing after spraying†
Unsprayed.....	....	1,132
None.....	9.6	30
1 per cent of oil emulsion A.....	7.4	44
3 per cent of oil emulsion A.....	12.9	7
1 per cent of tank-mix oil.....	7.3	49
3 per cent of tank-mix oil.....	13.7	0

* Sprayed November 23. Bordeaux made with quicklime.

† Infection before the spray was applied on November 23 resulted in an average of 146 lesions per 100 twigs. The values in this column were obtained by deducting this number from the average number of lesions per 100 twigs reported in table 4.

TABLE 6

IMPROVEMENT IN THE TENACITY OF BORDEAUX DEPOSIT AND THE CONTROL OF PEACH
BLIGHT WHEN PETROLEUM-OIL EMULSION WAS ADDED, 1937-38*

Treatment†	Deposit November 25, milligrams copper on 100 grams of twigs	February 27, milligrams copper on 100 grams of twigs	Per cent of copper lost	Per cent of twigs killed by the disease (April 15)
Bordeaux (10-10-100).....	29.3	6.4	88.2	14
Bordeaux (10-10-100) plus 4 per cent of emulsion A.....	27.5	11.0	60.0	5

* From data secured in a commercial orchard.

† Spray applied November 25. Bordeaux was prepared with hydrated lime, which was soaked 1 to 2 hours before using.

Some additional studies were made in a commercial orchard where bordeaux (10-10-100) alone and bordeaux (10-10-100) plus 4 per cent of oil emulsion A were applied. These studies (table 6) further demonstrated the increased tenacity attending the addition of a large amount of oil to bordeaux. Some improvement in control was also apparent.

As in 1936-37, leaf curl developed abundantly in unsprayed plots in the experimental orchard. No significant difference in control attended the various treatments listed in table 4; all gave excellent protection (table 3).

EFFECT OF PETROLEUM-OIL EMULSION ON THE AMOUNT OF BORDEAUX DEPOSITED ON A SURFACE

The unsatisfactory control of twig infection in 1936 (table 1) which attended the applications of bordeaux containing 1 per cent of oil-emulsion A and of B was attributed, in part at least, to the low initial

TABLE 7
EFFECT OF PETROLEUM AND COTTONSEED OILS ON THE RETENTION OF BORDEAUX MIXTURE BY PEACH TWIGS

Amount and type of oil added to bordeaux (10-10-100)	Milligrams of copper on 100 grams of twigs		
	1936	1937	1938
None.....	28.9	33.3	20.1
None.....	.....	29.6	.....
None.....	.....	36.0	.....
1 per cent of emulsion A.....	18.4	23.9	.....
2 per cent of emulsion A.....	24.9	.....	.....
3 per cent of emulsion A.....	20.4	26.5	20.1
4 per cent of emulsion A.....	40.9	.....	.....
1 per cent of emulsion B.....	16.6	.....	.....
2 per cent of emulsion B.....	34.4	.....	.....
1 per cent of tank-mix oil.....	.....	31.2	.....
3 per cent of tank-mix oil.....	.....	32.4	30.2
1 per cent of cottonseed oil.....	.....	28.9	24.9
2 per cent of cottonseed oil.....	.....	.....	24.6
Difference required for significance* { 19:1 odds.....	6.17	6.85	6.50
{ 99:1 odds.....	8.40	9.28	8.98
Calculated <i>F</i> value.....	18.21	2.76‡	3.74‡

* Differences required for significance at odds of 19:1 and 99:1 were obtained by multiplying the standard error of the difference by *t* values respectively as follows: 1936, 2.08 and 2.831; 1937, 2.064 and 2.797; 1938, 2.131 and 2.947.

† Exceeds *F* value for the 1 per cent point.

‡ Exceeds *F* value for the 5 per cent point.

deposit of the fungicide. A low deposit and unsatisfactory control were also recorded for the treatment containing 3 per cent of emulsion A: the amount of copper residue remaining on the trees in late February, shortly before the infection period that proved critical, was not materially lower than in treatments that remained effective during the critical period. On the other hand, treatments that controlled twig infection most satisfactorily—bordeaux containing 4 per cent of emulsion A and 2 per cent of emulsion B—gave initial deposits considerably higher than other treatments.

Whereas analysis of variance (table 7) shows that in 1936 the initial deposit of the bordeaux with 1 per cent of oil was significantly lower than that of bordeaux without oil, neither 1 per cent nor 3 per cent of

emulsion A significantly reduced deposits in 1937. In 1938, moreover, 3 per cent of emulsion A did not affect copper deposits. The treatment containing 3 per cent of tank-mix oil, on the contrary, deposited more copper than bordeaux without oil in 1938, but not in 1937. Considering these variations and the character of the results secured on almond in 1936 (table 2), at which time bordeaux plus 3 per cent of emulsion A deposited higher amounts of copper than bordeaux without oil, one can draw no definite conclusions regarding the effect of oil on initial deposits.

To obtain further information under laboratory conditions, a small spray applicator was constructed. This consisted of a framework at one end of which was attached a no. 16 De Vilbiss atomizer in a horizontal position; at the other end, 16 inches from the nozzle of the atomizer, a clamp held the object to be sprayed. A rubber tube led from the intake of the atomizer to a wide-mouthed glass jar holding the spray material. A small electric stirrer kept the spray material constantly agitated. The air blast to operate the atomizer was furnished by a laboratory pump equipped with an adjustable pressure-release valve. In order quickly to begin and end application without disturbing the delivery of spray from the atomizer, the nozzle was enclosed in a metal cup with an aperture in line with the stream of spray. This aperture was opened and closed by a shutter.

Though a number of improvements, such as that suggested by Horsfall, Heuberger, Sharvelle, and Hamilton (8) to control humidity, could be made in this apparatus, it was proved well suited to the purpose, which was to apply two or three different materials within a few minutes of each other.

Though Horsfall and his associates suggested as a standard surface that pyroxylin (cellulose nitrate) be dissolved in butyl acetate and deposited on glass, the present writer prepared the cellulose nitrate in the laboratory, and dissolved it in three parts of ether to one of alcohol. The surfaces were prepared by dipping microscope slides into this solution and standing the slides vertically in a dust-free atmosphere to dry for 24 hours.

Since the applicator was found to deliver bordeaux and bordeaux plus oil (hereafter called "oil-bordeaux" except where the type of oil is specified) at the same rate, some definite time or stage had to be established as an end-point in application. Evans and Martin (2) had applied the spray until the liquid began to run down the surface. Hoskins and Ben-Amotz (9), on the other hand, ended application after a measured amount of liquid had drained from the surface. In the present work certain considerations guided the decision to end application at the two

following stages: (1) at the point just before the liquid began to run down the surface (runoff stage), and (2) when about 1 cc of liquid had drained from the surface (drip stage). The considerations were as follows: assuming equal delivery of two materials from the atomizer, it is evident that at least during the early stages of application the liquid will be deposited at equal rates. If, therefore, two materials were applied for the same length of time, they should deposit the same amount, pro-

TABLE 8
EFFECT OF PETROLEUM-OIL EMULSION ON RETENTION OF BORDEAUX
DEPOSIT BY A CELLULOSE NITRATE SURFACE

Material	Stage at which application was stopped	Milligrams of copper on 1 square centimeter of surface
Bordeaux, 1 per cent.	Runoff*	0.0318
Bordeaux, 1 per cent, plus 3 per cent of emulsion A.	Runoff*	0.0343
Bordeaux, 1 per cent.	Drip†	0.0211
Bordeaux, 1 per cent, plus 3 per cent of emulsion A.	Drip†	0.0252
Difference required for { 19:1 odds .....	.....	0.0019
significance: { 99:1 odds .....	.....	0.0026

* Spraying was stopped when liquid showed signs of beginning to run down the surface.

† Spraying was stopped when 1 cc (approximately) of liquid had accumulated at the lower end of the slide.

vided one material did not begin to run off the surface before the other. The runoff stage provides, therefore, a criterion to judge retention of the liquid by the surface, for if one liquid is retained less than another this liquid will require the shorter period of application to reach the runoff stage. Since in practice one cannot spray all parts of the tree to exactly the same stage as regards runoff, one should determine whether overspraying causes differences in deposits; slides were, therefore, sprayed until about 1 cc of liquid had drained from the surface (drip stage).

Table 8 gives a typical example of spraying 10 slides each with bordeaux 1 per cent (8-8-100, approximately) and bordeaux 1 per cent plus 3 per cent of petroleum-oil emulsion A to the runoff stage and to the drip stage. The deposit of oil-bordeaux is seen to be significantly higher than that of bordeaux without oil when spraying was carried to either stage. According to these data, furthermore, significantly higher amounts of copper were present on surfaces sprayed only to the runoff stage than on surfaces sprayed until drip occurred.

In five such tests, when application ended at the runoff stage, bordeaux

with 3 per cent of oil emulsion increased deposits by 37 per cent, whereas the increase required for statistical significance at 99:1 odds was 21 per cent. In similar tests, when application was continued to the drip stage, oil-bordeaux increased deposits 26 per cent, whereas the increase required for significance at 99:1 odds was 20 per cent.

As was said earlier, the sprayer delivered oil-bordeaux and bordeaux at the same rate. If we assume, therefore, that the two materials were deposited on the surfaces at the same rate, the amount of each present at the runoff stage should differ only if the period of application necessary for producing runoff was longer with one than with the other. To test this point, one lot of bordeaux was divided into three portions. To the first was added 2 per cent of oil emulsion A; to the second, $\frac{1}{4}$ per cent of an organic spreading agent; to the third, nothing. The amount of bordeaux in all lots was adjusted to the same value by adding the requisite amount of water. In applying these materials to cellulose nitrate-covered slides, the time necessary to reach the runoff stage and the drip stage, respectively, was determined with a stop watch. On ten slides the average time necessary to produce runoff with bordeaux was 5.6 seconds; with bordeaux plus oil emulsion A, 7.2 seconds; with bordeaux plus the organic spreading agent, 4.4 seconds. The time necessary to reach the drip stage was 13.0, 16.1, and 9.7 seconds, respectively. Apparently, therefore, the time factor is one cause of the greater deposit of oil-bordeaux.

It is noteworthy that bordeaux with the spreading agent required the shortest application periods. Hockenyos and Irwin (6) found a similar situation when applying bordeaux with certain supplements to peach leaves. The present results with the spreader seem significant, furthermore, in view of the evidence by Evans and Martin (2) and Hoskins and Ben-Amotz (9) that an increase in the wetting and spreading quality of a spray material was frequently accompanied by a lower deposit. The relation of wetting and spreading to distribution of the deposit was next studied.

EFFECT OF OIL ON THE DISTRIBUTION OF BORDEAUX OVER THE SURFACE

According to studies by Evans and Martin (2), an accessory material that promotes wetting and spreading of the aqueous phase increases the uniformity with which the fungicide suspended therein is distributed over the sprayed surface. On surfaces particularly difficult for water to wet, the fungicide is deposited in unevenly distributed patches. Thus Yarwood (16) found bordeaux to be deposited on onion so unevenly as to be ineffective against the downy mildew fungus. When, however, a

spreading agent (Penetrol) was added, the bordeaux was distributed more evenly over the leaves and, in consequence, controlled the mildew more effectively.

Since peach twigs did not furnish a satisfactory surface for studying the effects of oil on distribution of bordeaux, the following tests were conducted with cellulose nitrate on glass slides. Bordeaux and oil-bordeaux exhibited little difference in the distribution of deposit on this surface when application was stopped before the runoff started. If, however, application was continued until 1 or 2 cubic centimeters of liquid had drained from the surface, the resulting deposit of oil-bordeaux was more even and finer in grain. The reason for this difference was clearly seen in observing the manner in which the bordeaux and oil-bordeaux drained from the surface. Whereas the former flowed down the slides in a series of drops which followed irregular courses and, in consequence, left uneven deposits of the solid, the oil-bordeaux flowed down the surface as a sheet, leaving the solid more evenly distributed.

When, immediately after deposition by spraying, the individual droplets of bordeaux and oil-bordeaux were more closely studied, those of the latter were found to cover somewhat smaller areas. To examine this point further, bordeaux, with and without different combinations of oil and a wetting agent were dropped from a 1-cc pipette from a height of 1 inch upon horizontal surfaces of cellulose nitrate. After 15 minutes the diameters of the drops were measured. The volume of the drops delivered by the pipette was established for each material. Table 9 gives data on the spread of drops, the volume of drop, and a percentage relation between these two data which was obtained by dividing the diameter of the drop (resting on the surface) by its volume. The ratios thus obtained were then expressed as a percentage of the ratio for water; that is, the value for water was considered as 100.

According to table 9 the diameter of spread of 1 per cent bordeaux was 90 per cent of that of water, whereas the spread of bordeaux plus 2 per cent of oil emulsion A was 63 per cent, and bordeaux plus oil without the emulsifier was even less. The spread of oil emulsion A (used alone) was practically the same as that of bordeaux plus oil emulsion A.

The organic spreading agent more than doubled the spread of water, noticeably increased the spread of bordeaux, and overcame the tendency for oil to restrict the spread of bordeaux. Since the amount of organic spreading agent was much more than the amount of emulsifier introduced into the spray with oil emulsion A, this is not a fair comparison of the spreading efficiency of the two. The differences in the results secured serve, however, to emphasize the relatively small influence the

emulsifier in emulsion A had on the spreading of oil-bordeaux under conditions favorable to spreading.

The conditions of these tests favored spread⁶ because the time interval elapsing between deposition and measurement of the drops allowed for possible extension of the liquid over the surface by capillarity. In this respect, among others, the conditions of the tests differ from those exist-

TABLE 9

EFFECT OF DIFFERENT MATERIALS ON THE AREA COVERED BY A DROP OF BORDEAUX MIXTURE ON A CELLULOSE NITRATE SURFACE

Material*	Mean diameter of drops on surface, millimeters†	Volume of drops, cubic centimeters	Percentage relations between data‡
Water	10.1	0.051	100
Bordeaux	8.9	0.050	90
Bordeaux, plus 2 per cent of oil emulsion A	6.1	0.049	83
Bordeaux, plus 2 per cent of tank-mix oil (emulsified by the bordeaux)	5.8	0.050	59
Oil emulsion A, 2 per cent, in water	6.4	0.050	65
Bordeaux, plus 2 per cent of tank-mix oil plus ½ per cent of organic spreader	6.5	0.033	99
Bordeaux, 1 per cent, plus ½ per cent of organic spreader	7.8	0.038	104
Organic spreader, ½ per cent in water	12.6	0.027	236
Difference required for significance: { 19:1 odds	0.7	.....	...
{ 99:1 odds	0.9	.....	...
Calculated <i>F</i> value	99.6	.....	...

* Bordeaux was prepared from 1 part of copper sulfate, 1 part of lime, and 100 parts of water, approximately 8-8-100.

† Measurements made 15 minutes after the material was deposited on the slide.

‡ The percentages were calculated as follows: By dividing the diameter of the drop on the surface by its volume, a ratio was obtained for each set of values. For water the ratio was considered 100 per cent; the others were referred to this basis.

ing under actual spray application. Where spray is applied, the liquid on the surface is constantly being disturbed by oncoming spray and, in consequence, the surface forces that determine its wetting and spreading properties do not attain equilibrium. The force of impact of spray with the surface is a second factor not of particular influence in these tests. Gravity in its tendency to pull the spray droplets down the vertical or inclined surface is a third factor that was not operative. Therefore, one cannot conclude that the same differences in the area covered by the individual droplets of bordeaux and oil-bordeaux will necessarily occur under actual spraying conditions. Some difference does exist, as was indicated by the observations, noted earlier, that the areas covered by

⁶ For a discussion of the wetting and spreading properties of liquids, and the influence of time on the expression of these properties, see Evans and Martin (2), Hensill and Hoskins (5), and Hoskins and Ben-Amotz (9).

individual droplets of the two types of bordeaux deposited by the applicator were not the same, those of oil-bordeaux being smaller than those of bordeaux. Whether an increase in the pressure of application would modify these differences is not known. A greater force of impact of spray with surface might force the droplets of oil-bordeaux to flatten out and cover a greater area even though the liquid did not wet this area. Droplets of bordeaux would probably be affected likewise.

Although the effect of impact pressure on spreading of the spray droplets was not studied, the following tests indicate that within the interval between deposition and drying, neither bordeaux nor oil-bordeaux spreads beyond the area they occupied when they were deposited. Drops were placed on horizontal cellulose nitrate surfaces in the manner described earlier. Their diameters were measured upon deposition and again after most of the water had disappeared. Whereas neither bordeaux nor bordeaux containing 3 per cent of oil emulsion A spread during this interval, bordeaux containing $\frac{1}{4}$ per cent of the organic wetting agent spread appreciably. Thus it would seem that the difference between the area covered by a given volume of bordeaux and oil-bordeaux was not due to difference in their spreading properties, but was probably (in part at least) the result of differences in wetting properties. A second factor, viscosity, also might have been partially responsible, but this phase was not studied.

The behavior of the solid (bordeaux precipitate) and oil phases was also observed during the drying of films deposited by the applicator. Whereas the solid phase showed no tendency to rearrange itself during this process, the oil behaved as follows: In freshly deposited drops the oil was visible as small globules enmeshed in the bordeaux precipitate. They retained their shape until most of the water had evaporated, but then broke from the emulsified state and spread over and among the solid particles. That the oil also deposited as a film on the surface was shown by the fact that an oil coating was left on the slides after the bordeaux had been removed with a weak acid.

EFFECT OF OIL ON TOXICITY OF BORDEAUX TO FUNGUS SPORES

If the release of soluble copper from the bordeaux film is requisite to toxic action, anything altering this release will affect toxicity. Holland, Dunbar, and Gilligan (7) believed that attempts to increase bordeaux tenacity might impair its toxicity. Goldsworthy and Green (4) claimed that some accessory materials rendered the particles of certain copper fungicides impervious to external solubilizing agencies.

Observations presented in the previous section suggest that when an oil-bordeaux film dries, the oil coats the bordeaux precipitate. At the time spray is applied the oil is dispersed as droplets among the bordeaux particles, but upon disappearance of water from the film the oil droplets were seen to break and spread over and among the bordeaux particles. The question of whether this coating of oil affected toxicity of bordeaux to fungus spores was studied.

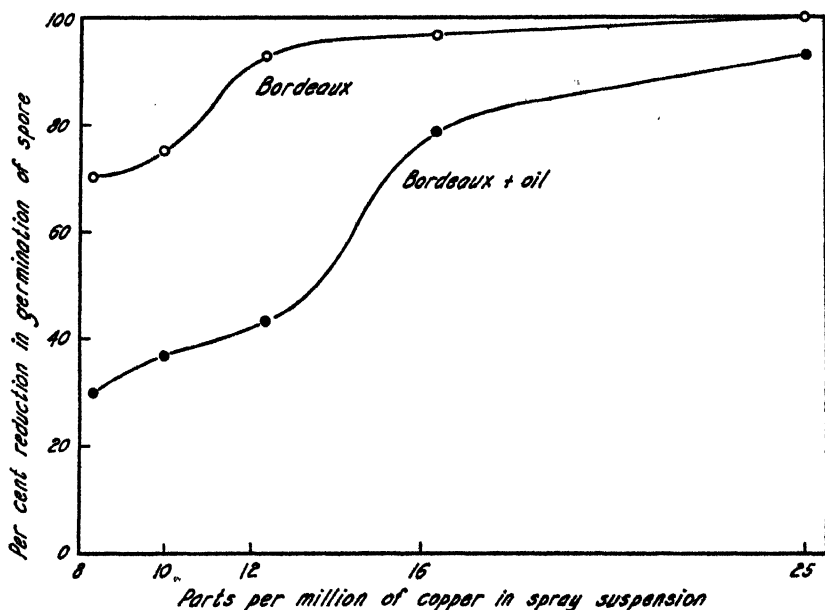


Fig. 1.—Effects of diluting bordeaux and bordeaux plus 3 per cent of oil on the toxicity of their dried films to germination of spores of *Coryneum Beijerinckii*. Undiluted (8–8–100) bordeaux of both types proved highly toxic, but with dilution oil-bordeaux was reduced in toxicity more rapidly than bordeaux.

As the tests showed, freshly prepared films of bordeaux (8–8–100) and of bordeaux (8–8–100) plus 3 per cent of oil have such uniformly high toxicity to spores as to make comparisons at this concentration impossible. Spores of neither *Coryneum Beijerinckii* nor *Sclerotinia fructicola* germinated when placed over the two types of dried films. The two types of bordeaux, therefore, were diluted successively; samples of each dilution were dried on glass slides; and spores of the two fungi suspended in sterile, distilled water were placed over the dried films. Figure 1 represents the percentages of reduction in germination of the spores of *Coryneum Beijerinckii*, plotted against parts per million of copper in the bordeaux suspension. Bordeaux was consistently more

effective in reducing germination than oil-bordeaux, both with *Coryneum Beijerinckii* and with *Sclerotinia fructicola*.

A second type of experiment was performed as follows: Bordeaux and bordeaux plus 2 and 4 per cent of oil emulsion A were diluted to contain 1 part of copper in 22,000 parts of water. Samples of these were deposited and dried on glass slides. An elongated drop of water, containing about 25 spores per low-power microscopic field, was so placed that one end

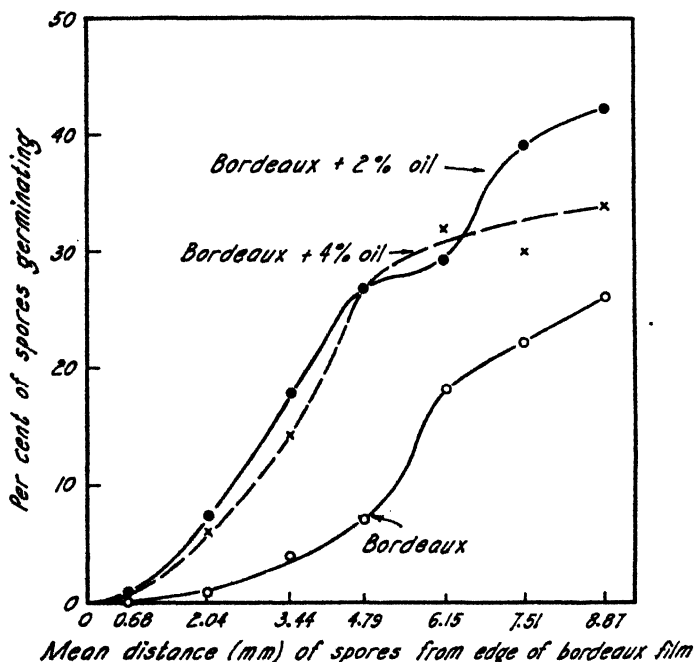


Fig. 2.—Effect of 2 and 4 per cent of oil emulsion on the toxicity of a dried deposit of bordeaux (8-8-100, diluted to contain 1 part of copper in 22,000 parts of water) to spores of *Coryneum Beijerinckii* lying in water at different distances from the deposit. Bordeaux suppressed germination more than oil-bordeaux at all distances from the deposit.

covered the bordeaux film, the other extending over clean glass for a distance of about 10 millimeters. After 24 hours the percentage of spores germinating was determined in zones located at different distances from the edge of the bordeaux film. According to the data in figure 2, no germination occurred when the spores were located over the film; but as the distance from the film increased, so did germination. The curve for germination over oil-bordeaux films rises more rapidly than that for germination over bordeaux films, indicating, as did the first type of experiment, a somewhat lower toxicity of oil-bordeaux.

These results represent the level of toxicity of freshly deposited bordeaux films only. That weathering alters the composition of a bordeaux film was recently demonstrated by Wilcoxon and McCallan (11), who found that the first change undergone—the carbonation of the excess lime—was completed within a few hours. The next change, brought about by rain, was the preferential removal of calcium and sulfate. When considerable amounts of these are removed the film becomes proportionately richer in copper. In freshly prepared bordeaux films, copper was only slightly soluble; but as leaching by rain continued, the solubility became greater.

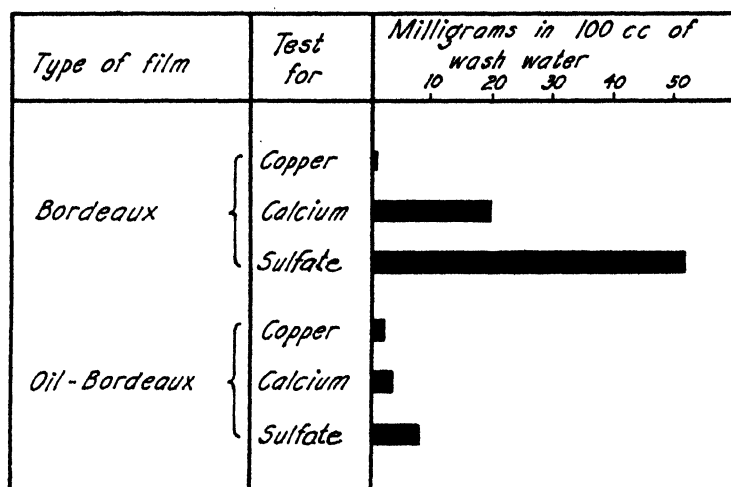


Fig. 3.—Effect of 3 per cent of oil emulsion on the amount of soluble copper, calcium, and sulfate leached from a bordeaux deposit with distilled water applied as "rain." Much of the copper lost from the oil-bordeaux deposit was dissolved in oil that escaped during leaching.

The effect of oil on leaching was therefore studied. Bordeaux (8-8-100) and bordeaux (8-8-100) plus 3 per cent of oil emulsion were deposited in equal quantities in uniform petri dishes. After drying for several days the plates were placed at a slight angle in separate funnels equipped with filter paper. Distilled water was atomized over the surfaces of the films for definite periods. The wash water was collected and analyzed for calcium, sulfates, and copper. In all cases oil retarded the loss of calcium and sulfates, but increased the loss of soluble copper from the films (fig. 3).

A slight turbidity of the wash water from oil-bordeaux film indicated that some material escaping from the film was capable of passing through filter paper. This material proved to be oil, which, upon extraction by

petroleum ether, proved to contain copper. In fact, most of the copper in the wash water was held by the oil. That the oil dissolves copper from the bordeaux residue was further shown by extracting oil-bordeaux film with anhydrous ether, after thoroughly drying the film in warm air for several hours. Upon evaporating the ether, incinerating the oil, and dissolving the residue in nitric acid, copper was found in considerable amounts.

Though the amounts of copper in wash water from the two types of films was not compared after long-continued leaching, the wash water from oil-bordeaux contained more copper than that from bordeaux at the end of the fourth 1-hour leaching. Obviously, as long as the oil is being removed from the film, the copper dissolved therein will also escape.

Whether or not the oil-dissolved copper renders the wash water more toxic to fungus spores than water from bordeaux films was the next problem. The following are results of a typical experiment: Spores of *Sclerotinia fructicola* suspended in water which had leached a bordeaux film for 20 minutes and into which had escaped 0.2 p.p.m. of soluble copper, and suspended in water which had leached an oil-bordeaux film for 20 minutes and into which had escaped 0.9 p.p.m. of soluble copper (most of which was dissolved in oil), germinated 73 and 61 per cent respectively, as compared with 89 per cent for the check. Other experiments with spores of *Coryneum Beijerinckii* indicated still smaller differences between the toxicities of wash waters from the two types of films. Under conditions of these experiments, therefore, the results were such as to suggest that the oil-dissolved copper escaping during leaching imparts little or no additional toxicity to the water. The results of toxicity studies presented in figures 1 and 2 are in accord with this conclusion, inasmuch as unleached oil-bordeaux was slightly less toxic than bordeaux.

DISCUSSION

The results secured in different phases of this study can now be related to one another. Attention is first directed to the evidence regarding loss of bordeaux from the sprayed surfaces. Wilcoxon and McCallan (11) described the changes that meteorological conditions effect in a bordeaux film after deposition. First, the excess lime is carbonated by action of carbon dioxide; second, rain leaches calcium and sulfates from the film; and third, the copper increases in solubility and is presumably washed away by rain. Just how rapidly copper is lost from the film by this leaching process is not known. It is probably slower than the loss that results when the bordeaux precipitate, as such, is removed from the surface by the eroding effect of rain. Since the field evidence secured

in this study does not distinguish between these two types of loss, the role played by oil in preventing loss of both types is not revealed. In laboratory "weathering" tests, however, the oil decreased the loss of calcium and sulfate by leaching. If, as indicated by Wilcoxon and McCallan's studies (11) water-soluble copper increased measurably only after disappearance of considerable calcium and sulfate from the film, then oil probably also delays leaching of copper. As will be remembered, the greater part of soluble copper escaping from oil-bordeaux film during laboratory weathering tests was dissolved in the oil; and the amount lost, in consequence, was limited to the dissolving power of the oil. The oil probably did not increase the amount of water-soluble copper, but very likely decreased it by protecting the bordeaux particles against the leaching effect of rain.

That oil protects the bordeaux from external weathering agencies might also be inferred from the observations that upon drying of an oil-bordeaux film the oil droplets broke from their emulsified state and spread over and among the bordeaux particles. The degree to which the bordeaux is oil-coated depends, of course, on the amount of oil used. In this connection one should remember that the tenacity of bordeaux increased with increasing amounts of oil. During the early stages of weathering the increased tenacity may very likely be due to a water-repellent property conferred upon the bordeaux and the surface by the oil. According to views expressed by Fajan and Martin (3), certain surface-active substances may reduce the tenacity of fungicides because they render the fungicide deposit more wettable by rain. Rendering the fungicide deposit less wettable by the addition of oil may therefore increase tenacity.

As certain emulsifying agents are good wetting agents, their tendency to increase the wetting properties of bordeaux film after it is deposited and dries should not be disregarded. In the present studies the emulsifier present in oil emulsion A was not shown to influence the wettability of the surface by the liquid oil-bordeaux. The reason for this might be that the emulsifier was not an active wetting agent; but a more likely explanation is that the emulsifier was present in the spray in such small amounts. When comparatively large quantities of an organic wetting agent were added to bordeaux, the wetting properties of the spray were increased. Possibly, therefore, an emulsifier that has high wetting powers and is used in amounts greater than in these tests might modify the tendency for oil to increase the tenacity of bordeaux.

Inasmuch as the evidence regarding the effect of oil on both the amount and the distribution of bordeaux deposit is intimately connected with

the wetting and spreading properties of the liquid, these phenomena must be considered. The wetting property of a liquid is that property which enables the liquid to make stable contact with the surface; the spreading property, on the other hand, determines the extent to which the liquid spreads over the surface by capillary forces (2, 5, 9, 15). The former determines the extent and the persistency of the contact of liquid with surface, and probably depends somewhat on time for maximum expression; the latter determines the final area covered by a given volume of liquid, and definitely depends on time for its maximum expression. In the present studies, the observation that upon hitting the surface the spray droplet did not run off, but occupied a certain area and assumed a definite shape, illustrated the degree to which the liquid wet the surface. If the surface proved nonwetttable, the droplets would roll off it without leaving a liquid deposit behind. Drops of bordeaux and oil-bordeaux placed upon a horizontal cellulose nitrate surface did not increase the area they occupied upon hitting the surface—an observation that illustrates the low capillary activity of the sprays on the particular surface. According to these tests, therefore, the addition of oil to bordeaux decreased the wettability of the latter, but did not affect the spreading properties. Hoskins and Ben-Amotz (9) found that an oil-water emulsion containing blood albumin or hemoglobin as the emulsifier would wet beeswax surfaces less easily than the corresponding water solutions of blood albumin or hemoglobin.

When bordeaux and oil-bordeaux were applied to a cellulose nitrate surface, the latter formed drops that occupied less area than those of the former. To cover a given area completely, therefore, a greater number of oil-bordeaux drops must be applied. Assuming that the time in application when the spray began to run from the surface was the point at which the surface was completely covered by liquid, then at this time the film of oil-bordeaux would be thicker than the film of bordeaux, because it requires longer application to produce runoff. Although this view fits the evidence secured, oil-bordeaux may have required a longer period of application than bordeaux to reach the runoff stage because it was more viscous and resisted the tendency of gravity to pull it from the position it occupied upon deposition (15).

From the beginning of application until the runoff stage the amount of deposit increased. When the liquid began to drain from the surface, however, no further increase could occur; on the contrary, the deposit of bordeaux decreased 33 per cent, and that of oil-bordeaux, 27 per cent. It was during the runoff stage that oil was found to improve the distribution of the bordeaux precipitate over the surface.

Though laboratory tests indicated oil-bordeaux to be slightly less toxic to fungus spores than bordeaux, the field tests revealed no such difference. The former, in fact, gave better control because it remained on twigs over a longer period. Under ordinary conditions, therefore, the slight effect of difference in toxicity is likely to be nullified by the greater effect of increased tenacity.

SUMMARY AND CONCLUSIONS

For adequate protection of peach trees against the attack of *Coryneum Beijerinckii* the twigs must be protected by a fungicide throughout the winter. The weather-resisting quality (tenacity) of the fungicide is therefore a determining factor in successful control. The primary purpose of field tests reported herein was to determine how certain added materials, particularly petroleum-oil emulsion, affect the tenacity of bordeaux mixture. The influence of oil on retention, coverage, and toxicity of bordeaux was studied in the laboratory.

When used in sufficient amounts, a dormant-type petroleum oil increased tenacity of bordeaux mixture. Thus 3 or 4 per cent decreased the loss of copper from peach twigs during the winter, but 1 per cent did not. This was true both of a commercial emulsion and of a tank-mix oil emulsion made with blood albumin.

By preventing loss of copper, the oil prolonged the period of protection afforded by a single treatment of bordeaux given in the autumn. In one year when *Coryneum Beijerinckii* attacked the twigs throughout the winter, the greater protective efficiency of oil-bordeaux was reflected in better control. In another year, however, when attacks of the fungus were confined to early winter, before rains had reduced copper deposits, bordeaux controlled the disease about as effectively as oil-bordeaux.

Neither bentonite (0.6 and 2 pounds per 100 gallons of spray) nor cottonseed oil (1 per cent) appeared to affect the tenacity of bordeaux or its control of twig infection by *Coryneum Beijerinckii*.

None of the added materials affected the efficiency with which bordeaux controlled leaf curl (caused by *Taphrina deformans*). A single autumn application of bordeaux, with or without added materials, effectively reduced the disease.

In certain field tests, oil appeared to affect the amount of bordeaux retained by peach twigs; but the results varied in such a way as to be inconclusive. Laboratory tests, therefore, were performed to determine the retention of bordeaux and oil-bordeaux by vertical surfaces of cellulose nitrate. The sprays were applied with an atomizing apparatus designed to deliver a constant volume of liquid.

When bordeaux and bordeaux plus 3 per cent of oil emulsion A were applied until the liquid showed signs of running down the surface, the latter deposited an average of 37 per cent more copper than the former. When application was prolonged until approximately 1 cc of liquid had run off the surface (drip stage), the latter deposited 26 per cent more copper than the former. With both types of bordeaux the deposit was greater at the runoff stage than at the drip stage. Between these two stages the copper deposit decreased 33 per cent for bordeaux, 27 per cent for oil-bordeaux.

In trials where the length of time necessary to produce runoff of the liquid from the slide was determined, oil-bordeaux was found to require the longer period.

The effect of petroleum-oil emulsion on coverage, or distribution of bordeaux over the cellulose nitrate surfaces, was observed by examining the area of surface covered by droplets sprayed onto slides. The area covered by a droplet of oil-bordeaux was found to be smaller than that covered by a droplet of bordeaux, as was also the case when equal-sized drops of the two types of bordeaux emitted from a pipette were allowed to fall from a fixed distance onto horizontal cellulose nitrate surfaces. As these drops neither extended nor contracted after deposition and before drying, spreading by capillary forces was apparently not present to any extent. Therefore, upon coming in contact with a surface during application, the area covered by the spray droplets was largely determined by the wetting properties of the liquid. As bordeaux wetted the surface somewhat better than oil-bordeaux, the droplets of this material occupied the larger area; and as fewer were required to cover the surface, less bordeaux than oil-bordeaux was required to produce runoff; hence less was retained by the surface. Difference in viscosity of bordeaux and oil-bordeaux might account, in part, for differences in deposits, although this phase was not studied. Application of the spray at a pressure higher than that employed in these tests might modify this difference in behavior between the two types of bordeaux. Force of impact would force the droplets to spread over areas they do not wet, although they might tend to withdraw from these areas after application ceases.

When application was prolonged until liquid had drained from the surface and the retained precipitate was dried, the oil-bordeaux was found more evenly distributed than the bordeaux. There is, apparently, an explanation: whereas bordeaux drained from the slide in a series of large drops which pursued an uneven course down the slide, leaving heavy and light deposits in their wake, oil-bordeaux drained from the surface as a sheet, leaving a more even deposit.

Though the laboratory results thus far are not adequate to explain the different problems encountered in the field, they contain suggestions that would account for wide variabilities in deposits between years, or between applications made by different individuals. For example, a tendency to end application at the time the spray begins to drip from the trees might give certain deposits, whereas a tendency to overspray might give different deposits.

The toxicities of the two types of bordeaux to spores of *Coryneum Beijerinckii* and *Sclerotinia fructicola* were compared in laboratory studies. Bordeaux mixtures (8-8-100), with and without oil, were of such uniformly high toxicity as to be indistinguishable in this regard. When, however, successive dilutions were made, bordeaux appeared to be somewhat more toxic than oil-bordeaux. Another method of assessing toxicity gave similar results. This method consisted in germinating spores of the two fungi in elongated drops of water, which were placed on slides with one end of the drop resting over a dried film of the fungicide, the other end extending for several millimeters over clean glass. The percentages of spores germinating were determined in zones at different distances from the edge of the fungicide deposit and were greater with oil-bordeaux than with bordeaux.

In artificial weathering tests, 2 per cent or more of oil emulsion was found to reduce the loss of calcium and sulfate from dried bordeaux films. As will be recalled, Wilcoxon and McCallan (11) found that during weathering, a loss of these two constituents was the forerunner of an increase in soluble copper in dried bordeaux films.

In tests of wash water from weathered bordeaux and oil-bordeaux films, more soluble copper was found to escape from the latter than from the former. It was determined, however, that most of the soluble copper was held by oil which escaped during the weathering process. Oil extracted from thoroughly dried oil-bordeaux films by anhydrous ether contained considerable amounts of soluble copper. The presence of this oil-held soluble copper did not appear to increase markedly the toxicity of the wash water to fungus spores.

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**PHYTOPHTHORA CINNAMOMI AND WET SOIL
IN RELATION TO THE DYING-BACK OF
AVOCADO TREES**

VINCENT A. WAGER

PHYTOPHTHORA CINNAMOMI AND WET SOIL IN RELATION TO THE DYING-BACK OF AVOCADO TREES^{1,2}

VINCENT A. WAGER³

INTRODUCTION

A DYING-BACK or decline of avocado trees has become a serious problem to growers in some parts of southern California during the last few years.⁴ The trees affected are usually those that are fairly old (ten or more years of age), and the trouble may occur in isolated trees or, more commonly, in groups of trees in an orchard.

Horne (7)⁵ describes this decline under the various names of melanorhiza, water injury, asphyxiation, apoplexy, and collapse, and associates it with such conditions as excess water, lack of aeration, and heavy subsoils, not with any particular organisms.

Affected trees appear to lose vitality; they become sparsely foliated, fail to produce crops, and their branches begin to die back. Such trees have been seen occasionally growing in sandy soil where drainage conditions would appear to be good. But in many instances, when holes were dug alongside of these trees, an impervious subsoil was found about 2 feet below the surface.

The possibility that at times the decline of the trees is caused by too much water, cannot be overlooked. In one instance, a hole approximately 3 feet deep was dug in an affected orchard some 10 days after a period of continuous, fairly heavy rain in midwinter. In about 15 minutes, water began to ooze out of the sides of the hole, at a depth of about 2 feet from the surface of the ground, and to trickle to the bottom.

Roots of most of the trees examined were found to be blackened and dead, especially the fibrous roots and those up to $\frac{1}{8}$ inch in diameter. Larger roots, $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter, also, were sometimes soft, brown,

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² Paper No. 455, University of California Citrus Experiment Station, Riverside, California.

³ Plant Pathologist, Union of South Africa Department of Agriculture. On Commonwealth Fellowship in collaboration with the Division of Plant Pathology, University of California Citrus Experiment Station, Riverside, California, September, 1939, to June, 1940.

⁴ Mr. M. B. Rounds places the number of acres of avocados affected with this trouble, conservatively, at 500.

⁵ Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

and rotten and had a disagreeable odor. When the thin bark of the large roots was scraped with a knife, brown lesions $\frac{1}{4}$ to $\frac{3}{4}$ inch in size were often seen, usually at the junction of a small root which was dead. When the thin bark of healthy roots is scraped, the underlying tissue is found to be white and crisp; in affected roots this tissue is brown and soft.

A few large trees have been known to die suddenly. One such tree was a twenty-five-year-old avocado with a trunk nearly 18 inches in diameter. All the leaves of this tree withered and died suddenly during the month of September, 1939, after a period of particularly hot weather, and many of its roots were found to be blackened and dead. The theory was advanced that the tree, which was standing in a slight depression, had, during the winter, received too much water; that many roots had consequently become infected with fungi and had died; and that, possibly, the sudden heat had caused excessive transpiration, with which the reduced root system could not cope.

FUNGI FOUND ON ROOTS OF AVOCADO

Cultures were made from 156 roots from affected avocado trees growing in seven different localities. In each case, cultures were made from fibrous roots, from small roots $\frac{1}{8}$ inch in diameter, and from larger ones $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter; cultures were also made from lesions on the big roots. A *Phytophthora* species was found on 37 roots from six of the seven localities, *Pythium* species were found on 21 roots from all seven localities, and *Fusarium* species on most of the remaining 98 roots from all localities. The *Phytophthora* species was found generally in the lesions and on the larger-sized roots—very seldom on the fibrous roots. The *Pythium* species were usually on the fibrous and smaller-sized roots.

The *Phytophthora* species found in the cultures was identified as *Phytophthora Cinnamomi* Rands. The *Pythium* species were identified as *Pythium vexans* de Bary (on 20 roots) and *Pythium ultimum* Trow (on 1 root). Two other fungi which very frequently appeared in these cultures were *Fusarium oxysporum* Schl. and *Cylindrocarpon radicicola* Wr.*

PHYTOPHTHORA CINNAMOMI RANDS

This is the first record of *Phytophthora Cinnamomi* on avocados in the United States. All the cultures obtained were found to be similar. The fungus grows well on various culture media and produces a tough, wiry, aerial mycelium.

Hyphae are as much as $8\ \mu$ in diameter and covered with irregularly shaped protrusions, with numerous septations in the hyphae in older

* These two fungi were identified by W. C. Snyder, Assistant Professor of Plant Pathology and Assistant Plant Pathologist in the Experiment Station.

cultures. Chlamydospores occur in bunches on short stalks and are usually spherical and thin-walled. In diameter, they range from 18 to 48 μ , are commonly 42, and average 37.8 μ . Oögonia are spherical and terminal; they range from 27 to 48 μ and average 37 μ in diameter. In color, they are golden brown. The oöspore practically fills the oögonium and is spherical and thick-walled. Antheridia are rounded, about 12 μ in diameter, and amphigynous. Sporangia are thin-walled, nonpapillate, and produced on long, thin hyphae; they vary from 30 to 80 $\times$ 20 to 45 μ in size. In one batch of material they were commonly 40 $\times$ 25 μ ; in another, 60 $\times$ 40 μ ; in a third, 75 $\times$ 45 μ . The sporangial stalk may continue to grow through and out of an empty sporangium and produce another; or, more commonly, new sporangia may develop within the old, empty sporangium. Sporangia were produced in abundance when the fungus, grown on sterilized wheat, was placed in running water. As many as 16 zoöspores were seen in a sporangium. They are actively motile on liberation and soon round off to a diameter of 10 μ .

Rands (10) in his description of this fungus gives measurements of chlamydospores as 28 to 60 μ , average 41 μ ; sporangia, 25 to 100 $\times$ 18 to 43 μ , average 57 $\times$ 33 μ ; oöspores were not observed. Ashby (1) found that oögonia averaged 32 μ in diameter. Tucker (11) obtained oögonia 28 μ in diameter. Thus, except for larger oögonia, the description of the fungus found in the avocado cultures is very similar to other descriptions of *Phytophthora Cinnamomi*. The oögonia obtained in the present study were from 3-month-old cultures in oatmeal tubes, which had been standing in the laboratory during the winter months.

Phytophthora Cinnamomi had previously been obtained from the roots of avocado trees suffering from dieback in South Africa (14). The fungus was very similar to that described above: the chlamydospores ranged from 26 to 43 μ and were commonly 32 μ in diameter; oögonia were from 30 to 52 μ in diameter and averaged 41.4 μ ; sporangia were 39 to 66 $\times$ 26 to 40 μ , commonly 50 $\times$ 32 μ .

There appears to be considerable confusion in literature with regard to the taxonomy of *Phytophthora Cinnamomi* and *P. cambivora* (Petri) Buis. The latter is responsible for the "ink disease" of chestnuts in Europe. White (16) and Mehrlich (8) agree that the two fungi are but strains of the same species and hence retain the prior name of *P. cambivora*. Tucker,¹ however, states that he is inclined to agree with Ashby (1) in his retention of the two species, and this view has been adopted in the present study.

Phytophthora Cinnamomi has been recorded as follows: on cinnamon

¹ Tucker, C. M., in letter to author dated April 27, 1940.

(*Cinnamomum Burmanni* Bl.) in Sumatra (10); on chestnut (*Castanea sativa* Mill.) in England (4); on avocado (*Persea americana* Mill.) in Puerto Rico (11) and in South Africa (13); on American chestnut (*Castanea dentata* [Marsh] Borkh.), hairy chestnut (*C. mollissima* Blume), Japanese chestnut (*C. crenata* Blume), Japanese yew (*Taxus cuspidata* Sieb. and Zucc.), Norway spruce (*Picea Abies* [L.] Karst.), red pine (*Pinus resinosa* Ait.), Scotch pine (*P. sylvestris* L.), Colorado spruce (*Picea pungens* Engelm.), black walnut (*Juglans nigra* L.), Persian walnut (*J. regia* L.), birch (*Betula papyrifera* Marsh), oak (*Quercus borealis* Michx., *Q. montana* Willd., *Q. alba* L.), plane (*Platanus orientalis* L.), and locust (*Robinia Pseudo-Acacia* L.) in the southeastern United States (3); on rhododendrons (*Rhododendron californicum* Hook., *R. carolinianum* Rehd., *R. ponticum* L.) in the United States (16); on walnut in Australia; on heath (*Erica* sp.) in the United States and (*Erica hyemalis* Nichols, *E. nivalis* Andr., $\times$ *E. Willmorei* Knowles and Westc.) in England (9); and on sour orange (*Citrus Aurantium* L.) infected with gummosis in Brazil (5). *P. Cinnamomi* has also been reported in connection with wilt produced by inoculation in *Antirrhinum*, *Calceolaria*, *Schizanthus*, and beech (*Fagus* sp.) seedlings in England (9); and as causing a rot of pineapples (*Ananas sativus* Schult.) in Hawaii, Queensland, Costa Rica, Jamaica, Cuba, Haiti, and the Philippines (9). The fungus was recently isolated by W. T. Horne from lesions or cankers on the trunk of a Nabal avocado tree that was dying in San Diego County, California.

Temperature Requirements.—This fungus makes good growth over a fairly wide range of temperatures. The strain from South Africa grew well at temperatures ranging from 16° to 31° C, while that from citrus in Brazil made good growth also at 34°, the optimum for the former being 25° and for the latter, between 28° and 31° (15). The temperature requirements for the California fungus were not determined, but they are probably somewhat similar to those given above.

Soil Acidity in Relation to *Phytophthora Cinnamomi*.—White (16), in a study of rhododendron wilt caused by *Phytophthora Cinnamomi*, found that 60 to 100 per cent infection took place in infected soils ranging in pH value from 4.0 to 7.3. In a plot having a pH value below 4.0, only 1 plant out of 15 wilted; and in plots having a pH value above 7.3, there was 33 per cent mortality.

According to Haas (6), avocado seedlings grow better both in culture solutions and in soils having low pH values, the lowest tested being pH 4.5.

PYTHIUM SPECIES

Pythium vexans de Bary has not been previously recorded from avocado. This fungus was isolated from 20 different avocado roots from seven localities in southern California. It grows well on most culture media and has a distinctive type of growth suggestive of combed silk. The hyphal main branches are as much as 6μ in diameter; side branches are thin (2μ), and the tips are curly. Oögonia are spherical and terminal, usually on short side branches; commonly 18 to 22μ , they average 20μ in diameter. Antheridia have a large surface in contact with the oögonia and are usually funnel-shaped; they usually have a fairly long branch and may arise from a hypha not directly connected to the oögonium. Sporangia are generally spherical and terminal on short stalks (occasionally intercalar) 15 to 27μ , mostly 21μ , in diameter. Zoöspores are produced very readily, the evacuation tube being usually one half to one third as long as the diameter of the sporangium. Zoöspores were 7 to 8μ in size, and the number produced in various sporangia ranged from 7 to 12.

This description agrees very closely with that of de Bary and with that of Braun (2) for the fungus he described as *Pythium complectens* Braun, which name, according to Middleton,^{*} should be discarded in favor of *P. vexans*.

Pythium vexans was found in South Africa on papaya, or pawpaw (*Carica papaya* L.) infected with foot rot, and on perennial statice, or thrift (*Armeria* sp.), infected with wilt or crown rot (14). Middleton (see footnote 8) lists this fungus from the following hosts: alfalfa (*Medicago sativa* L.), sugar cane (*Saccharum officinarum* L.), durian (*Durio zibethinus* L.), pan (*Piper betle* L.), pipri (*P. longum* L.), stock (*Mathiola incana* [L.] R. Br.), castor bean (*Ricinus communis* L.), geranium (*Pelargonium* sp.), coleus (*Coleus* sp.), flax (*Linum usitatissimum* L.), rocket larkspur (*Delphinium Ajacis* L.), ginger (*Zingiber officinale* Roscoe), rubber (*Hevea brasiliensis* Muell.), carnation (*Dianthus Caryophyllus* L.), potato (*Solanum tuberosum* L.), and spinach (*Spinacea oleracea* L.). It was recently isolated on several occasions from the fibrous roots of citrus trees suffering from decline in California (15).

Pythium ultimum Trow was isolated from 1 root only. This is the first record of its occurrence on avocados. The fungus was typical of

^{*} Middleton, John T. Taxonomy of the genus *Pythium* Pringsheim. Thesis in partial fulfillment of the requirements for the degree of Doctor of Philosophy, University of Missouri, 1940. (Typewritten.) Copy on file in the Library of the University of Missouri, Columbia.

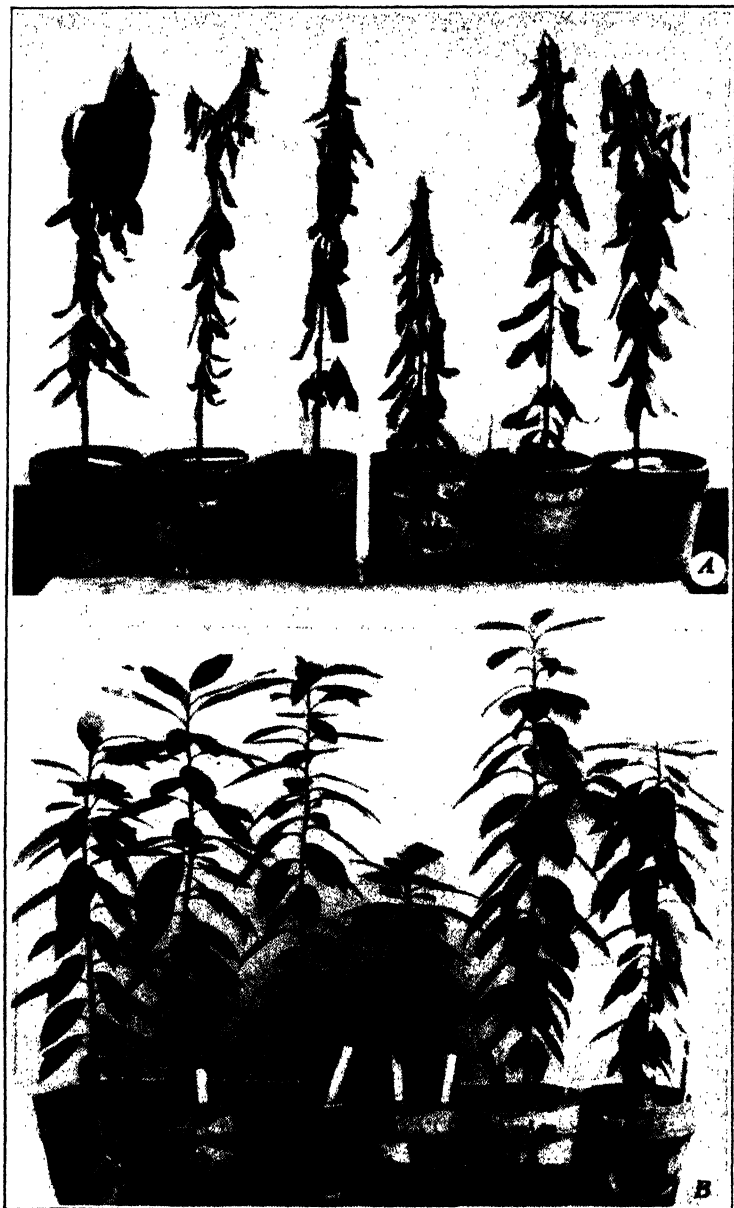


Fig. 1.—*A*, *Phytophthora Cinnamomi* was added to the soil of each of these pots; a month later the 3 pots on the left were submerged for 2 days, the other 3 for 3 days. The pots were photographed 1 week later; by this time the avocado plants had wilted and died. *B*, No fungus was added to the soil in these pots; the 3 pots on the left were submerged for 3 days, the other 3 for 9 days. None of the plants subsequently showed any ill effects.

the species. *Pythium ultimum* is found commonly on citrus (15), but as it apparently plays little or no part in this avocado trouble, it is not discussed further in the present paper.

INOCULATION EXPERIMENTS

Previous inoculation experiments by the writer, in Africa, had indicated that under normal soil conditions *Phytophthora Cinnamomi* does not affect avocado plants adversely. Tucker (see footnote 7, p. 521), also, states that avocado plants growing under healthy conditions were not



Fig. 2.—*Phytophthora Cinnamomi* was added to the soil in the 4 pots on the left. Controls, on the right, were untreated. Soil in all pots was watered when necessary. Six months later all avocado plants were still healthy.

affected when the fungus was added to the soil; but if the pots were allowed to stand in saucers containing 1 inch of water, the plants rapidly wilted, while uninoculated controls treated in the same manner remained healthy. A series of experiments was therefore planned with the idea of simulating possible field conditions, where, as a result of continuous heavy rains or faulty irrigation practice, the soil becomes flooded and waterlogged for a short period of time. Tests were primarily with *Phytophthora Cinnamomi*, but a few tests with *Pythium vexans* were included in experiments 1 and 2.

Experiments 1 and 2.—For these experiments, trees two to three years old, growing in pots (figs. 1 and 2), were used. The soil in some pots was inoculated with *Phytophthora Cinnamomi*, that in other pots was inoculated with *Pythium vexans*, and that in the control pots was untreated. The fungi were grown in tubes of sterilized wheat kernels and

TABLE 1

EFFECT ON POTTED AVOCADO PLANTS OF INOCULATION OF SOIL AND SUBMERSION OF
ROOTS IN WATER FOR VARIOUS PERIODS OF TIME

Experiment no., inoculation treatment, and test no.	Plants	Timesub- merged	Results
	number	days	
Experiment 1:			
No fungus added to soil (controls):			
Test 1.....	4	0	Remained healthy; roots normal
Test 2.....	4	1	Remained healthy; roots normal
Test 3.....	4	3	Remained healthy; roots normal
<i>Phytophthora Cinnamomi</i> added to soil:			
Test 1.....	4	0	Three months later, all plants healthy; a few roots black and dead
Test 2.....	4	1	After 1 week, 2 plants slightly wilted (showed com- plete recovery after 2 months); 2 plants severely wilted and showing large number of roots black- ened
Test 3.....	4	3	After 1 week, 2 plants dead, 2 severely wilted; roots mostly black and dead; lesions on main tap- roots; fungus recovered from most roots
<i>Pythium vezans</i> added to soil:			
Test 1.....	4	0	Remained healthy
Test 2.....	4	3	Remained healthy, except 1 plant which showed slight wilt after 1 week but recovered
Experiment 2:			
No fungus added to soil (controls):			
Test 1.....	4	3	Remained healthy; roots normal
Test 2.....	4	6	Remained healthy; roots normal
Test 3.....	4	9	Remained healthy, roots normal, except 1 plant which wilted and died 1 week later (<i>Pythium</i> <i>ultimum</i> isolated from blackened roots of this plant)
<i>Phytophthora Cinnamomi</i> added to soil:			
Test 1.....	6	2	Plants wilted after submersion; 2 plants recovered; 4 plants dead 1 week later; <i>Phytophthora Cinna-</i> <i>momi</i> recovered from most dead roots
Test 2.....	6	3	Plants wilted after submersion; all dead 1 week later
<i>Pythium vezans</i> added to soil:			
Test 1.....	4	2	Remained healthy
Test 2.....	4	3	Remained healthy

then introduced into a shallow hole in the top layer of the soil in the pots without injuring any roots. A month was allowed for the fungus to grow throughout the soil. Pots of each series were then immersed in larger containers of water for varying periods of time, after which the pots were lifted out of the water and allowed to drain rapidly. Results are presented in table 1.

TABLE 2

EFFECT OF INOCULATION WITH *Phytophthora Cinnamomi* ON AVOCADO PLANTS GROWN IN SOLUTION IN FLASKS

Experiment no., inoculation treatment, and test no.	Plants	Treatment of nutrient solution	Results
Experiment 3 (in laboratory; temperature about 23.9° C [75° F]):	number		
No treatment (controls):			
Test 1.....	3	Aerated	All plants remained healthy, but those aerated were more robust and developed more new roots than those not aerated
Test 2.....	3	Non-aerated	
<i>Phytophthora Cinnamomi</i> :			
Test 1.....	3	Aerated	After 1 week, all plants showed wilt and brown roots; after 2 weeks, all plants were dead
Test 2.....	3	Non-aerated	
Experiment 4 (in greenhouse; temperature 32.2° to 37.8° C [90° to 100° F]):			
No treatment (controls):			
Test 1.....	3	Aerated	All plants remained healthy, but those aerated had grown and produced more roots than those not aerated
Test 2.....	3	Non-aerated	
<i>Phytophthora Cinnamomi</i> :			
Test 1.....	3	Aerated	Wilted more slowly than similarly treated plants of experiment 3; dead after 3 weeks
Test 2.....	3	Non-aerated	

Experiment 3.—The soil was washed carefully from the roots of 6 avocado plants about 1 foot high. Sterilized wheat on which *Phytophthora Cinnamomi* was growing was scattered on the roots of these plants, which were then wrapped in damp paper for 2 days. Each plant was then placed in a 3-liter flask containing nutrient solution. Air was bubbled through the solution in 3 flasks, but not through that in the other 3.

Six other plants were used as controls. These plants were given the same treatment as that described in the preceding paragraph, except that there was no fungus on the wheat which was scattered on the roots.

All plants were kept in the laboratory, where temperatures reached about 23.9° C (75° F) and there was little air movement, so that transpiration was low.

Results of these tests are presented in table 2.

Experiment 4.—The soil was washed carefully from the roots of 12 avocado plants about 1 foot high. Each plant was placed in a 1-liter flask containing nutrient solution, and air was bubbled through the solution in all the flasks for 1 week.

Phytophthora Cinnamomi grown on sterilized alfalfa stalks and stimulated to produce sporangia and zoöspores freely by placing in running water,⁹ was inserted in the neck of each of 6 flasks; sterilized stalks without the fungus were placed in the other 6 flasks, which served as controls. Air was bubbled through the solution in 3 of the flasks in each series, but not through that in the other 3.



Fig. 3.—Avocado plants in flasks containing nutrient solution through which air was bubbled continuously. *Phytophthora Cinnamomi* was placed in contact with the roots of the 3 plants on the right. The photograph was taken 10 days later, by which time these 3 plants had wilted and died. In a second similar series, not aerated, the results were indistinguishable from those shown here.

All plants were kept in the greenhouse, where temperatures reached 32.2° to 37.8° C (90° to 100° F) daily and transpiration was high.

For the results of these tests see table 2 and figure 3.

Conclusions.—If not overwatered, avocado plants can apparently remain in soil inoculated with *Phytophthora Cinnamomi* for at least 3 months without showing any ill effects; and when *Phytophthora Cinnamomi* was not present in the soil, the plants could be submerged for periods of 3, 6, or even 9 consecutive days without suffering any ill effects. But if this fungus is in the soil and the roots and soil are sub-

⁹ Method from L. J. Klotz.

merged for 2 or 3 days (even 1 day is apparently sufficient), the plants are liable to attack; the roots turn black, and the plants rapidly wilt and die.

Plants in soil containing *Pythium vexans* showed no ill effects from 2 or 3 days' submersion.

Plants growing in a solution without aeration for a period of 3 weeks made little foliage or root growth, but otherwise appeared to remain normal. Those well-aerated produced new foliage and large numbers of roots. Zoöspores and mycelium of *Phytophthora Cinnamomi* added to plants growing in solution caused wilting and death, irrespective of whether the solution was aerated or not.

DISCUSSION

That avocado trees cannot stand excessive water at their roots appears to be recognized fact.¹⁰ Dying-back, or decline, of the trees can generally be expected under such a condition, whether this be the result of faulty irrigation practice, heavy or continuous rains, a leak in a pipe line, or lack of drainage due to impervious subsoil fairly near the surface. Dying-back may occur even in sandy soils under excessively wet conditions. Many of the roots may be destroyed without apparently affecting the tree until several months later, when, with drier weather, the depleted stock of roots is unable to supply the tree adequately with nourishment, and dying-back becomes evident. The cause of the decline may then appear baffling, for at that time no sign of the excessive water conditions can be observed or would perhaps even be suspected.

The results of the present experiments may possibly throw some light on the problem. Too much water, alone, may not be the cause of the death of the roots, for it would seem that the fungus *Phytophthora Cinnamomi* plays an important part. The results of these experiments have confirmed those of earlier tests (12, 13) and show that this fungus does not attack the roots or affect the health of plants grown in soil where drainage is good and water is not excessive. But when the roots are allowed to stand in nonmoving water for even as short a period of time as 24 hours, they become susceptible to attack by the fungus; and the longer the period, the more drastic the results. On the other hand, roots immersed for 3 days in experiment 1 and for 9 days in experiment 2, in soil in which *Phytophthora Cinnamomi* was not present, were not affected at all. In fact, Horne (7) states that the roots of 2 healthy potted plants were immersed, and only after the eighteenth day did they wilt and subsequently die.

¹⁰ This was emphasized by Dr. J. E. Coit in a lecture to the Avocado Department of the Los Angeles Farm Bureau at Whittier, California, February, 1940.

Apparently, avocado roots can stand immersion for certain lengths of time without harmful effects, unless *Phytophthora Cinnamomi* is present, when immersion, even for a short time, will cause injury. One may speculate that, with a lack of oxygen, cell activity and normal respiratory processes may cease, accumulations of substances in the cells may take place, or the outer layer cells of the root may be weakened or killed. Under moist conditions, zoöspores of the fungus would be produced. These zoöspores might be more virulent than the fungus mycelium in attacking the roots; but this hardly seems likely, for in a heavy soil saturated with water they would probably only be able to swim about on the soil surface. It remains to be determined in what manner the fungus brings about the injury. Dead roots of the wilted plants were found to be permeated with hyphae. If unfavorable conditions are not prolonged beyond a safe limit and if no fungus is present, the vital processes which have been slowed up or stopped in the cells apparently resume normal operation when normal soil conditions are restored, without injury to the roots.

Experiments showed that *Pythium vexans* was unable to attack and harm roots immersed for as long as 3 days. It is likely, therefore, that this fungus, although found frequently in the cultures, grows in weakened or dead roots, or in those attacked by *Phytophthora Cinnamomi*.

Pythium ultimum was found on only 1 root and was disregarded in this investigation.

No tests for the pathogenicity of *Fusarium oxysporum* and *Cylindrocarpon radiclecola* were carried out, but it is suspected that they would prove no more harmful than *Pythium vexans*.

SUMMARY

Dying-back, or decline, of avocados in southern California appears to be commonly associated with excessive moisture.

Roots of affected trees are frequently blackened and dead, and the larger roots may have brown lesions on them. Two fungi, *Phytophthora Cinnamomi* Rands and *Pythium vexans* de Bary, were commonly isolated from such roots.

Phytophthora Cinnamomi had previously been recorded from avocados only in South Africa and in Puerto Rico.

In inoculation experiments it was found that if the plants were watered normally, *Phytophthora Cinnamomi* could be present in the soil for at least 6 months without affecting them seriously. If the roots of the plants and the soil were flooded or submerged for 2 or 3 days, or for but 24 hours, however, the fungus caused injury to the roots, followed by rapid wilting and subsequent death of the plants.

Control plants, in tests where no fungus was present, could withstand such flooding for as long as 9 days without suffering any subsequent harm.

The results of tests with *Pythium vexans* indicate that this fungus does not injure the roots but probably grows only in weakened or dead roots or in those already attacked by *Phytophthora Cinnamomi*.

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PYTHIACEOUS FUNGI ON CITRUS

VINCENT A. WAGER

PYTHIACEOUS FUNGI ON CITRUS^{1,2}

VINCENT A. WAGER³

PYTHIACEOUS FUNGI on citrus in California were investigated during the season 1939-40. In the course of this investigation, citrus roots were examined for the presence of fungi, inoculation experiments were performed on citrus fruits with pythiaceous fungi from citrus in general, and growth-temperature relations of *Phytophthora* species found on citrus were studied. This paper reports the results of this work, and includes a compilation of records on the geographic distribution of *Phytophthora* on citrus and a description of all *Phytophthora* and *Pythium* species recorded on citrus.

PYTHIACEOUS FUNGI ON ROOTS OF CITRUS

In previously reported work on the isolation of fungi from roots of citrus, Fawcett (3)⁴ states that species of *Pythium* and *Phytophthora* have been found to be associated with the damping-off and death of young citrus trees. Weindling (11) isolated *Phytophthora parasitica* Dastur and *Pythium* spp. from citrus seedlings affected with this disease in California, and Perlberger (5) found *Phytophthora citrophthora* (Sm. and Sm.) Leonian and *Phytophthora parasitica* in the same connection in Palestine. Fawcett (1) recorded the finding of *Phytophthora citrophthora* and *Phytophthora parasitica* in 1923 on large citrus roots and showed that the former would attack small roots of lemon trees. He (2, 3) also found *Phytophthora megasperma* Drechsl. on the fibrous roots of orange trees dying back in heavy clay soil in Tulare County, California. In 1935, Petri (6) found *Pythium megalacanthum* de Bary and *Pythium de Baryanum* Hesse associated with root rot of oranges in Catania, Italy.

In order to explore the possibility that species of *Phytophthora* or some other fungi might be playing a more active part in producing disease in citrus trees in California than had hitherto been suspected, large numbers of roots were examined from citrus trees that showed a

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² Paper No. 456, University of California Citrus Experiment Station, Riverside, California.

³ Plant Pathologist, Union of South Africa Department of Agriculture. On Commonwealth Fellowship in collaboration with the Division of Plant Pathology, University of California Citrus Experiment Station, Riverside, California, September, 1939, to June, 1940.

⁴ Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

dying-back, or decline. Orange and lemon trees growing in various localities in southern California were inspected.

Roots from the diseased trees were carefully washed in water; portions of the dead fibrous roots, about 1 cm long, were then surface-sterilized and placed on petri dishes poured with oatmeal agar. Culture tests were made from 320 fibrous roots of orange and 152 fibrous roots of lemon. The nonpythiaceous fungus *Fusarium Solani* (Mart.) App. and Wr.⁵ was found on most of the roots from all localities.⁶ Table 1 shows the pythiaceous fungi found and the frequency of their occurrence.

TABLE 1
PYTHIACEOUS FUNGI ISOLATED FROM FIBROUS ROOTS OF CITRUS TREES
VARIOUSLY LOCATED*

Fungus	Orange roots		Lemon roots	
	Number of localities where found	Number of roots infected, of 320 tested	Number of localities where found	Number of roots infected, of 152 tested
<i>Phytophthora citrophthora</i>	4	6	1	3
<i>Phytophthora parasitica</i>	1	1	0	0
<i>Pythium de Baryanum</i>	1	1	0	0
<i>Pythium rostratum</i>	1	1	0	0
<i>Pythium ultimum</i>	9	31†	3	7
<i>Pythium vexans</i>	2	3	1	2

* Root samples were from citrus trees in 22 different localities.

† Of these roots, 20 (of 24 tested) were from 1 locality.

Pythium ultimum Trow was the fungus most frequently found in these root samples, occurring on 38 out of 472 roots from 12 out of 22 localities. *Phytophthora citrophthora* was next, occurring on 9 roots from 5 localities. *Pythium vexans* de Bary was found on only 5 roots from 3 localities; and the other fungi (table 1) came from only 1 locality each. The absence of a given fungus from a few samples of roots from a

⁵ Identified by W. C. Snyder, Assistant Professor of Plant Pathology and Assistant Plant Pathologist in the Experiment Station.

⁶ Culture tests made from roots of citrus trees affected with a condition known as "dry root rot" have generally yielded *Fusarium Solani*. Attempts by various workers (3), however, to reproduce the disease by inoculation, with this fungus, of trees growing under healthy conditions, have yielded negative results.

To test the possible effect of *Fusarium* further, large numbers of young citrus trees, including some three-year-old trees growing in 5-gallon cans, were inoculated with the *Fusarium Solani* common in the more recent isolation tests by introducing the fungus, growing on sterilized wheat kernels, into the top layers of the soil without disturbing the roots. A month later, a number of these plants were submerged in larger containers of water for periods varying from 3 days to 3 weeks. They were then drained rapidly and were watered thereafter whenever necessary. During the following 6 months, none of these plants showed any ill effects from the presence of the fungus or from the period of submersion.

given tree is not much of an indication, however, that it was not to be found on that tree. In a study of fungi on avocado roots (10), *Pythium ultimum* was found on 1 root and *Pythium vexans* on 20.

INOCULATION OF CITRUS FRUIT WITH PYTHIACEOUS FUNGI

Inoculations were made on orange and lemon fruits with all the pythiaceae fungi recorded by Fawcett (3) and by Fawcett and Bitancourt (4), namely, *Phytophthora citrophthora* (Sm. and Sm.), *Phytophthora parasitica* Dastur, *Phytophthora palmivora* Butler, *Phytophthora Syringae* Kleb. (= *P. hibernalis* Carne), *Phytophthora cactorum* (L. and C.) Schroet. (= *P. citricola* Saw.), *Phytophthora megasperma*, and *Phytophthora Cinnamomi* Rands; and by Wager (8, 9), namely, *Pythium irregulare* Buis. from a rotting orange and *Pythium ultimum* Trow from the navel end of a young orange. These fungi included all the Pythiaceae previously obtained from citrus, with the exception of *Pythium megalacanthum* de Bary.

The relative importance of deep and shallow wounds (that is, those which penetrate the juice sacs and those which do not) in the production of rots caused by *Alternaria Citri* Ellis and Pierce and *Fusarium lateritium* Nees has been demonstrated (9). Accordingly, in these tests, inoculum (fungus growing on agar) was placed on the surface of the fruit and in shallow wounds, being covered in both cases with damp absorbent cotton; or it was placed in deep wounds made with a cork borer and sealed with vaseline. The results are presented in table 2.

Phytophthora citrophthora, *P. parasitica*, *P. palmivora*, and *P. cactorum* produced a brown rot of fruits, whether the inoculum was placed on the surface of the uninjured fruit or in shallow or deep wounds. The fruits inoculated with *P. Syringae* were kept at 18° C; there was no infection through uninjured epidermis, and the rot developed very slowly both in shallow and in deep wounds.

Phytophthora megasperma did not produce infection through uninjured epidermis, but did induce a slow, brown, leathery rot through shallow or deep wounds. *P. Cinnamomi* was also unable to pierce uninjured epidermis; through wounds, it produced a firm, brown, leathery rot, which was inclined to be of a drier type inside than that produced by the other species.

Pythium ultimum and *Pythium de Baryanum* were able, in a few cases, to infect through uninjured skin. Both of these fungi, through shallow or deep wounds, produced a brown rot and wrinkling of the skin, grew rapidly to the core, and traveled to both ends of the fruit,

TABLE 2
INFECTION OF CITRUS FRUITS BY INOCULATION WITH PYTHIACEOUS FUNGI

Fungus, culture no., and source of culture	Number of fruits infected (of 3 inoculated) and rate of infection (R, rapid; S, slow)				
	Oranges		Lemons		
	Surface inoculation	Deep wound	Surface- inoculation	Shallow wound	Deep wound
<i>Phytophthora cactorum</i> :					
2016,* from lemon fruit, Brasil.....	3 R	3 R	3 R	3 R	3 R
292,† from grapefruit, South Africa....	3 S	3 S	2 S	3 S	2 S
<i>Phytophthora Cinnamomi</i> :					
2009,* from orange bark, Brasil.....	0	3 R	0	3 R	3 R
385,‡ from avocado root, South Africa....	0	3 S	0	3 S	3 S
6, from avocado root, California.....	0	3 S	0	3 S	3 R
15, from avocado root, California.....	0	3 S	.....	.....	.....
<i>Phytophthora citrophthora</i> :					
1309,* from lemon bark, California....	3 R	3 R	3 R	3 R	3 R
3222,† from orange fruit, South Africa....	3 R	3 R	3 R	3 R	3 R
29, from orange root, California.....	2 S	3 R	3 R	3 R	3 R
52, from lemon root, California.....	2 R	3 R	.....	.....	.....
<i>Phytophthora megasperma</i> :					
1851,* from orange root, California....	0	3 S	0	3 S	2 S
<i>Phytophthora palmivora</i> :					
2003,* from orange bark, Argentina....	2 S	3 S	2 S	3 R	3 R
<i>Phytophthora parasitica</i> :					
2011,* from orange bark, Brasil.....	3 S	3 R	3 R	3 R	3 R
32,‡ from orange root, California.....	3 R	3 R	3 R	3 R	3 R
<i>Phytophthora Syringae</i> :					
1894,* from orange fruit, California....	0	3 S	0	3 S	3 S
1839,* from orange fruit, California....	0	3 S	0	3 S	3 S
<i>Pythium de Baryanum</i> :					
13, from orange root, California.....	0	3 R	1 R	3 R	3 R
<i>Pythium irregulare</i> :					
90, from orange fruit, South Africa....	0	1 S	0	2 S	1 S
<i>Pythium rostratum</i> :					
37, from orange root, California.....	0	0	0	0	0
<i>Pythium ultimum</i> :					
1, from orange root, California.....	1 R	3 R	0	3 R	3 R
42, from lemon root, California.....	1 R	3 R	1 S	3 R	3 R
<i>Pythium vexans</i> :					
30, from orange root, California.....	0	3 S	0	3 S	3 S
38, from orange root, California.....	0	3 S	0	3 S	3 S

* Isolated by Fawcett.

† Isolated by Doidge.

‡ Isolated by Wager.

which then also showed infection. The decay was a much softer and slushier type than that produced by the *Phytophthora* species. *Pythium irregulare* behaved similarly, but was much less virulent and rotted only a few of the inoculated fruits. *Pythium vexans* produced a distinctive rot both in shallow and in deep wounds; it progressed slowly, developed a sunken, brown, slushy area with a water-soaked zone surrounding it,

TABLE 3
GROWTH-TEMPERATURE RELATIONS OF *Phytophthora* SPECIES

Fungus, culture no., and source of culture	Radial growth* of fungus after 4 days at 25° C and 4 days at different temperatures													
	1°	4°	7°	10°	13°	16°	19°	22°	25°	28°	31°	34°	37°	
<i>Phytophthora cactorum</i> :	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	
2016, † from lemon fruit, Brazil.....	0	0	3	5.0	9.5	15.5	17.0	22.0	27.5	28.0	4.0	0.0	0	
292, † from grapefruit, South Africa.....	0	0	4	10.0	15.0	22.0	27.5	28.5	24.0	23.5	5.0	1.5	0	
<i>Phytophthora Cinnamomi</i> :														
2009, † from orange bark, Brazil.....	0	0	0	0.0	3.0	15.5	16.5	21.0	20.0	21.5	21.5	20.0	0	
388, ‡ from avocado root, South Africa.....	0	0	0	2.5	11.0	22.5	30.5	38.0	41.0	37.0	22.5	2.0	0	
<i>Phytophthora citrophthora</i> :														
1309, † from lemon bark, California.....	0	0	3	4.5	10.5	14.5	16.5	19.5	21.0	21.0	18.5	6.0	0	
190, ‡ from grapefruit bark, South Africa.....	0	0	0	5.0	13.0	20.0	22.0	25.5	32.0	31.5	27.5	2.0	0	
322, ‡ from orange fruit, South Africa.....	0	0	0	5.5	13.5	19.0	27.0	29.0	28.5	25.0	20.0	2.0	0	
<i>Phytophthora megasperma</i> :														
1851, † from orange root, California.....	0	2	8	12.0	16.5	20.0	22.5	19.5	15.5	17.5	2.0	0.0	0	
<i>Phytophthora palmitora</i> :														
2003, † from orange bark, Argentina.....	0	0	0	0.0	3.5	8.5	17.0	22.0	25.0	23.5	23.5	17.0	4	
<i>Phytophthora parasitica</i> :														
2011, † from orange bark, Brazil.....	0	0	0	0.0	4.0	18.0	22.5	24.5	29.0	30.0	32.0	27.0	5	
<i>Phytophthora Syringae</i> :														
1894, † from orange fruit, California.....	0	2	3	5.0	5.5	5.5	1.0	0.0	0.0	0.0	0.0	0.0	0	
1339, † from orange fruit, California.....	0	0	6	6.0	9.5	7.0	2.0	0.0	0.0	0.0	0.0	0.0	0	
296, † from orange fruit, South Africa.....	0	0	4	8.0	11.0	11.0	1.0	0.0	0.0	0.0	0.0	0.0	0	
* Average of three cultures. † Isolated by Fawcett. ‡ Isolated by Dodge. § Isolated by Wager.														

* Average of three cultures.

† Isolated by Fawcett.

‡ Isolated by Doidge.

§ Isolated by Wager.

and was soft and slushy inside. *Pythium rostratum* Butler and one strain of *Pythium vexans* (with coiled antheridial branch) did not produce any infection at all.

GROWTH-TEMPERATURE RELATIONS OF PHYTOPHTHORA SPECIES

The growth-temperature relations of *Phytophthora* species, based on radial growth of the mycelium in culture, are shown in table 3. The results agree with those of Fawcett and Bitancourt (4). *P. parasitica* has a slightly higher maximum than *P. citrophthora*; and *P. parasitica*, *P. palmivora*, and *P. Cinnamomi* from citrus in Brazil grew well at 34° C. *P. Syringae* is a low-temperature fungus, not growing at 22° or above and showing maximum growth between 13° and 16°. *P. megasperma* also has a low maximum, 19°.

DISTRIBUTION OF PHYTOPHTHORA SPECIES ON CITRUS

The world distribution of the *Phytophthora* species on citrus, as compiled from Fawcett's (3) records and from a survey of phytopathological literature up to 1940, is as follows:

Phytophthora cactorum:

Argentina
Brazil
Japan
South Africa

Portugal

Sicily
South Africa
Southern Rhodesia
Spain

Phytophthora Cinnamomi:

Brazil
United States—California

United States—California and Florida
West Indies, including Puerto Rico

Phytophthora citrophthora:

Argentina
Australia—New South Wales, Queensland, South Australia, Victoria, and West Australia
Azores
Belgian Congo
Brazil
Cyprus
Egypt
India
Italy
Japan
Mexico
Mozambique
New Zealand
Palestine

Phytophthora megasperma:

United States—California

Phytophthora palmivora:

Argentina
Ceylon
East Indies, including Java
India
Malaya
Philippine Islands
Surinam
Tanganyika Territory
Uruguay
West Indies, including Puerto Rico and Trinidad

Phytophthora parasitica:

Argentina
Australia—New South Wales
Azores

Phytophthora parasitica (continued)

Brazil
Cuba
East Indies—Java
Italy
Japan
Mexico
Palestine
Paraguay
Philippine Islands
Portugal
Sicily
Spain

United States—California and Florida
Uruguay
West Indies, including the Lesser Antilles, Puerto Rico, and Trinidad

Phytophthora Syringae:

Australia—New South Wales, South Australia, Victoria, and West Australia
Azores
Portugal
South Africa
United States—California

IDENTIFICATION OF PYTHIACEOUS FUNGI ON CITRUS

For convenience in identifying Pythiaceae found on citrus, the characteristics of *Phytophthora* species are given in table 4 (see also fig. 1), and those of *Pythium* species in table 5 (see also fig. 2). All cultures described in these tables were examined by the writer except *Pythium megalacanthum*.

According to Tucker (7), the names *Phytophthora hibernalis* and *P. citricola* should be discarded in favor of *P. Syringae* and *P. cactorum*, respectively. Fawcett's cultures 1894 *P. Syringae* and 1839 *P. hibernalis* were found very similar in their cultural and morphological characters and in their reactions when inoculated into citrus fruits and are herein considered to be *P. Syringae*.

TABLE 4

MORPHOLOGICAL AND PHYSIOLOGICAL CHARACTERS OF *Phytophthora* SPECIES ON CITRUS

Fungus, culture no., and source of fungus	Characters of the isolates used in this study					Characters recorded in original description of species
	Distinguishing characters	Oögonia and oöspores	Antheridia	Chlamydo-spores	Sporangia	
<i>Phytophthora cactorum</i> (L. and C.) 2018, from lemon fruit, Brazil	Profuse production of oögonia with parasitagnous antheridia	Oögonia 18-42, commonly 30-40 in diameter; oöspores about 6 μ less; light yellow-brown	Paragynous	Only a few seen; 26 μ in diameter; thin-walled, not colored	Papilla not prominent; 20-30 $\times$ 25-40 μ in size; sparsely produced	Oögonia average 26-29 μ in diameter; chlamydo-spores very scarce; sporangia 25 $\times$ 32-42 μ in size
202, from grapefruit, South Africa	Profuse production of oögonia with parasitagnous antheridia	Oögonia 28-33, average 29.3 μ in diameter	Paragynous	16-33, commonly 30 μ in diameter	20-36 $\times$ 43-73 μ , average 31 $\times$ 58 μ in size	Oögonia average 26-29 μ in diameter; chlamydo-spores very scarce; sporangia 25 $\times$ 32-42 μ in size
<i>Phytophthora Citreovora</i> (Sim. and C.) 2002, from orange bark, Brazil	Production of chlamydo-spores in bunches	Oögonia 28-36, commonly 33 μ in diameter; very rare in culture; oöspores 3-5 μ less in diameter, with very thick wall	14-18 μ in diameter; amphigynous; golden-brown	15-50, commonly 40 μ in diameter; occurring in bunches; thin-walled	Ovoid; nonpapillate; 25-35 $\times$ 40-70 μ , commonly 30 $\times$ 50 μ in size; proliferous	Oögonia average diameter 32 μ (Ashby) or 25 μ (Tucker); chlamydo-spores 28-60, average 44 μ in diameter; sporangia 18-43 $\times$ 25-100 μ , average 33 $\times$ 57 μ in size
<i>Phytophthora citrophthora</i> (Sim. and Sim.) 1309, from lemon bark, California	Absence of oögonia; optimum growth at 25-27.5° C, none at 32.5°	Not found	Not found	Spherical; thin-walled; 20-40, commonly 30-35 μ in diameter	Prominently papillate; 12-40 $\times$ 20-50 μ , commonly 25 $\times$ 40 μ in size	Oögonia unknown; chlamydo-spores commonly 28 μ in diameter; sporangia 20-40 $\times$ 30-90 μ , average 35 $\times$ 50 μ in size; may retain a pedicel
130, from grapefruit bark, South Africa	Absence of oögonia; optimum growth at 25-27.5° C, none at 32.5°	Not found	Not found	Very rare; 25-30 μ in diameter	20-40 $\times$ 23-50 μ , average 35 $\times$ 41 μ in size	Oögonia unknown; chlamydo-spores commonly 28 μ in diameter; sporangia 20-50 $\times$ 30-40 μ , average 35 $\times$ 50 μ in size; may retain a pedicel
<i>Phytophthora myosmyces</i> Drechsel. 1381, from orange rock, California	Large size of oögonia and absence of chlamydo-spores	Oögonia 30-54, average 43 μ in diameter; oöspores about 6 μ less, with thick yellow wall	12-15 μ in diameter; usually paragynous but may be amphigynous	Not found	Ovoid or sometimes papillate; 25-42 $\times$ 33-64 μ , commonly 35 $\times$ 40 μ in size; proliferous	Oögonia 16-61, average 47.4 μ in diameter; sporangia 6-45 $\times$ 16-90 μ in size

TABLE 4—(Continued)

<i>Phytophthora palmivora</i> Butler: 2003,* from orange bark, Argentina	Absence of oögonia; optimum growth at 27.5–30° C.; will grow at 32.5°	Not found	Not found	Produced in abundance; spherical; may be intercalary; 23–40, commonly 30 μ in diameter; thin-walled	Prominently papillate; 22–35 $\times$ 35–55 μ , commonly 32 $\times$ 40 μ in size	Oögonia produced only in paired cultures; oöspores 22–24 μ in diameter; antheridia amphigynous; chlamydospores 32–42 μ in diameter; sporangia 25–35 $\times$ 40–60 μ in size, with short, stout pedicel
<i>Phytophthora persicae</i> Dastur: 2011,* from orange bark, Brazil	Optimum and maximum growth temperatures about 3° higher than that for <i>P. citrophthora</i>	Oögonia 27–36, commonly 32 μ in diameter; oöspores 3–5 μ less, thick-walled, yellow-brown	Mainly amphigynous	Produced in abundance; 27–42, commonly 30 μ in diameter; thin- or thick-walled; may be yellow	Prominently papillate; 15–30 $\times$ 19–45 μ , commonly 28 $\times$ 40 μ in size	Oögonia group microspora, 12–24 μ in diameter, average under 20 μ ; macrospora 20–36 μ in diameter, average over 20 μ ; chlamydospore $\pm$ 30 μ in diameter; sporangia average more than 25 $\times$ 30 μ in size
32,† from orange root, California	Optimum and maximum growth temperatures about 3° higher than that for <i>P. citrophthora</i>	Oögonia 24–33, commonly 30 μ in diameter		28–54, commonly 30 μ in diameter	21–45 $\times$ 24–40 μ , commonly 35 $\times$ 45 μ in size	Oögonia group microspora, 12–24 μ in diameter, average under 20 μ ; macrospora 20–36 μ in diameter, average over 20 μ ; chlamydospore $\pm$ 30 μ in diameter; sporangia average more than 25 $\times$ 30 μ in size
<i>Phytophthora Syringae</i> Kleb.: 1894,* from orange fruit, California	Grows at low temperatures; optimum growth at 13–16° C	Oögonia 27–36, commonly 32 μ in diameter; oöspores 3–5 μ less, thick-walled, light yellow	Small, 9–12 μ in diameter; paragynous	Not found	Papilla, flattened or protruding but without hyaline plug; 15–18 $\times$ 24–42 μ , commonly 18 $\times$ 30 μ in size; thin persistent, pedicel 10–25 μ long	Oögonia, average diameter 28.4 μ (Tucker); 40.8 μ (Carne); sporangia 15–33 $\times$ 28–41 μ , average 17.9 $\times$ 34.4 μ (Tucker), 16.1 $\times$ 34.6 μ (Carne)
206,‡ from orange fruit, South Africa	Grows at low temperatures; optimum growth at 13–16° C	Oögonia 26–40, commonly 35.2 μ in diameter		Not found	15–25 $\times$ 26–57 μ , commonly 20 $\times$ 37.5 μ in size	Oögonia, average diameter 28.4 μ (Tucker); 40.8 μ (Carne); sporangia 15–33 $\times$ 28–41 μ , average 17.9 $\times$ 34.4 μ (Tucker), 16.1 $\times$ 34.6 μ (Carne)

* Isolated by Fawcett.

† In one test with *Phytophthora cactorum*, a culture on oatmeal agar was flooded with pea broth, and sporangia were produced in abundance, very irregular in shape, mostly elongated, and very variable in size (45–90, commonly 60 $\times$ 30 μ).

‡ Isolated by Dodge.

§ This fungus from citrus was compared with *Phytophthora Cinnamomi* from roots of avocado from South Africa and from California. All were found to be very similar morphologically and all produced oögonia on oatmeal-agar tubes that had been kept in the laboratory over winter and were 3 to 6 months old.

¶ Isolated by Wager.

TABLE 5
MORPHOLOGICAL AND PHYSIOLOGICAL CHARACTERS OF *Pythium* SPECIES ON CITRUS

Fungus and source of culture	Characters of isolates used in this study			Characters recorded in original description of species*
	Oögonia and oöspores	Antheridia	Sporangia	
<i>Pythium de Baryanum</i> Hesse, from orange root,†† California	Oögonia 16-26, commonly 20 μ in diameter; usually terminal; may be intercalar; oöspores about 3 μ less in diameter	Commonly 1 or 2 per oögonium, may be more; arise on same hyphae as, and some distance from, the oögonium or on separate hyphae	14-28, commonly 22 μ in diameter; terminal and spherical or may be intercalar and oval; thin-walled; production of zoospores not observed	Oögonia 15-28, average 21 μ in diameter; sporangia 15-26, average 19 μ in diameter; zoospores produced
<i>Pythium irregulare</i> Buia, from orange fruit,‡ South Africa	Oögonia 16-24, commonly 22 μ in diameter; may be terminal; mostly intercalar; spherical, oval, irregularly lobed, or with few blunt, digitate spines; oöspores about 3 μ less in diameter	Commonly 2 or 3 per oögonium; clavate and crooked; usually with fairly long stalk arising from same or neighboring hyphae	13-28 μ in diameter; very variable in shape; terminal and spherical or may be intercalar and elliptic or irregular in shape; evagination tube usually $\frac{1}{3}$ to $\frac{1}{2}$ length of oögonium	Oögonia 16-18 μ in diameter; sporangia 10-20 μ in diameter; zoospores produced
<i>Pythium neoplascentum</i> de Bary,§ from orange root,¶ Italy	Oögonia 36-45 μ in diameter, exclusive of spines; terminal or intercalar; about 10-14 μ long; conical, acutely tipped; oöspores smooth	One or more per oögonium; dichinous	Terminal or intercalar; spherical to subspherical; frequently proliferous, forming a second prominent, short, thick primary; zoospores produced	Oögonia 42-54 μ in diameter; sporangia frequently proliferous; zoospores produced
<i>Pythium rostratum</i> Butler, from orange root,†† California	Oögonia 12-27, commonly 21 μ in diameter; occasionally terminal; usually intercalar; may occur in chains; oöspores usually filling oögonia	Usually 1, rarely 2 or 3 per oögonium; may arise at base of oögonium or may be a portion of oögonial stalk; sometimes swollen	15-27, commonly 24 μ in diameter; usually spherical; may be intercalar and oval, or barrel-shaped; thin-walled; production of zoospores not observed	Oögonia usually 21 μ in diameter and intercalar; sporangia 23-34, average 28 μ in diameter; zoospores produced
<i>Pythium ultimum</i> Trow, from orange root,†† California	Oögonia 18-24, commonly 21 μ in diameter; usually terminal and spherical; may be intercalar; oöspores about 3 μ less in diameter	Usually 1, curved, arising immediately below the oögonium; may arise out of from a different hypha	16-26, commonly 21 μ in diameter; usually terminal and spherical; may be intercalar, thin-walled	Oögonia 19.6-22.9, average 20.6 μ in diameter; sporangia 12-28, average 20 μ in diameter; zoospores not produced
<i>Pythium sezzens</i> de Bary, from orange root,††§ California	Oögonia 15-24, commonly 20 μ in diameter; mostly terminal; few intercalar; oöspores about 3 μ less in diameter	Usually 1, rarely 2 per oögonium; swollen, clavate or bell-shaped, usually on long branch arising from hypha bearing oögonium	12-26, commonly 22 μ in diameter; usually terminal and spherical; may be intercalar and elliptic or irregular in shape; evagination tube usually $\frac{1}{3}$ to $\frac{1}{2}$ length of oögonium	Oögonia 15-28, average 22 μ in diameter; sporangia 17-24, average 21 μ in diameter; zoospores produced

* Middleton. John T. Taxonomy of the genus *Pythium* Fringsheim. Thesis in partial fulfillment of the requirements for the degree of Doctor of Philosophy, University of Missouri, 1940. (Typeset.) Copy on file in the Library of the University of Missouri, Columbia.

† Filicous roots.

‡ Isolated by Wager.

§ This fungus was not seen by the writer; the description given is that of its author, de Bary.

¶ One found by the writer; isolated from lemon rootlets.

†† One found by the writer; isolated from lemon rootlets.

††§ One found by the writer; isolated from lemon rootlets.

§ One found by the writer; isolated from lemon rootlets.

¶ One found by the writer; isolated from lemon rootlets.

†† One found by the writer; isolated from lemon rootlets.

††§ One found by the writer; isolated from lemon rootlets.

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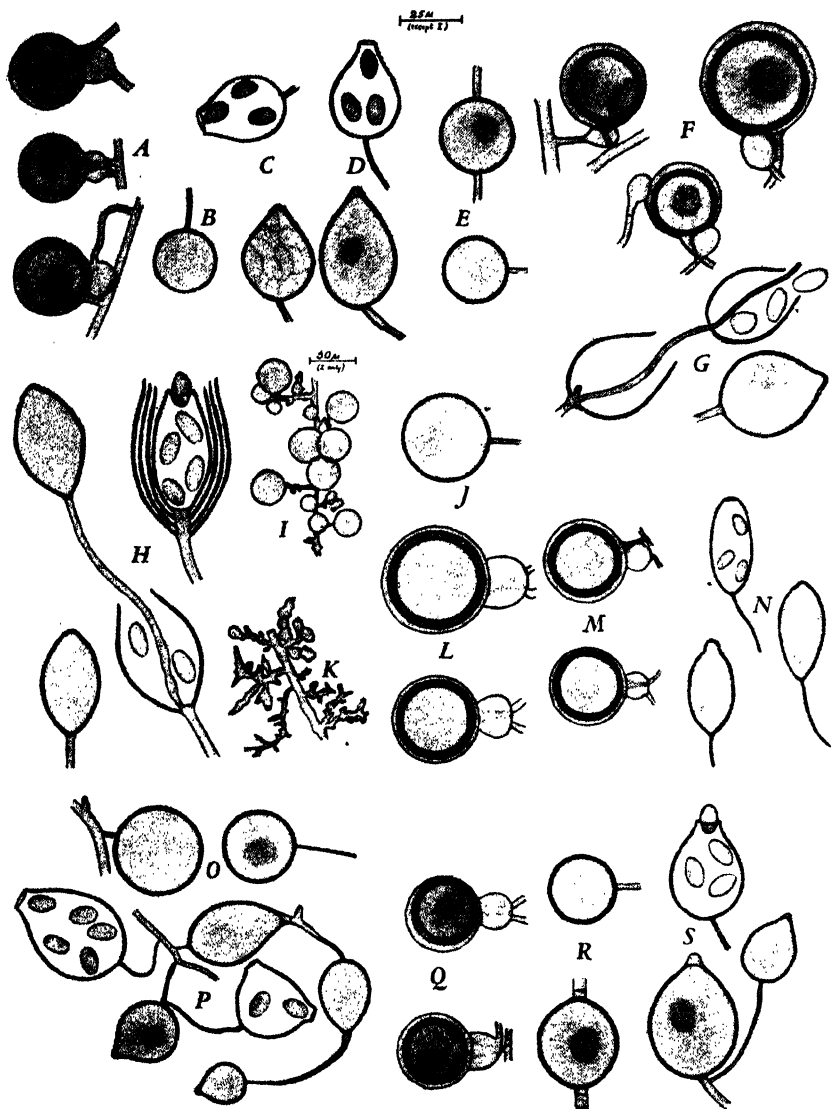


Fig. 1.—*Phytophthora* species. A–C, *Phytophthora cactorum* (L. and C.) Schroet.: A, oogonia and paragnynous antheridia; B, chlamydospore; C, sporangia. D–E, *Phytophthora palmivora* Butler: D, sporangia; E, chlamydospores. F–G, *Phytophthora megasperma* Drechs.: F, oogonia and paragnynous antheridia; G, sporangia. H–L, *Phytophthora Cinnamomi* Rands: H, sporangia; I, J, chlamydospores; K, mycelium; L, oogonia and amphigynous antheridia. M–N, *Phytophthora Syringae* Kleb.: M, oogonia and paragnynous antheridia; N, sporangia with persistent pedicels. O–P, *Phytophthora citrophthora* (Sm. and Sm.) Leonian: O, chlamydospores; P, sporangia. Q–S, *Phytophthora parasitica* Dastur: Q, oogonia and amphigynous antheridia; R, chlamydospores; S, sporangia.

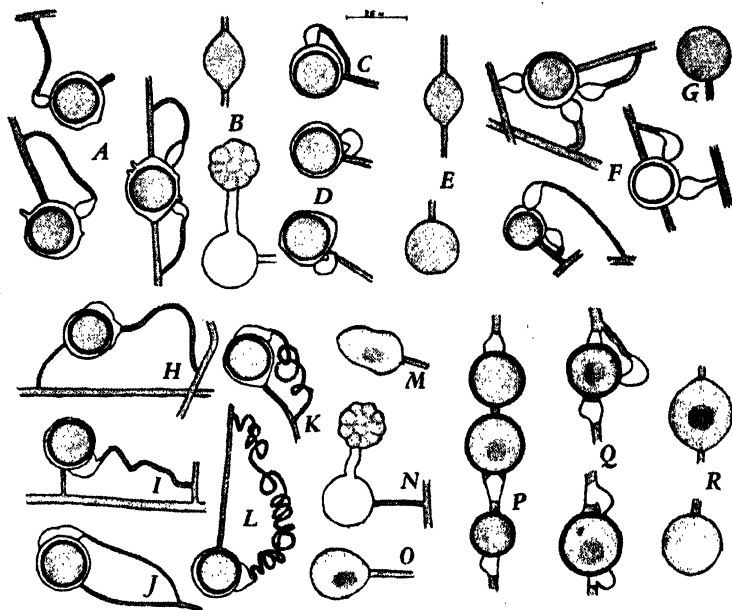


Fig. 2.—*Pythium* species. A–B, *Pythium irregulare* Buis.: A, antheridia and oogonia; B, sporangia. C–E, *Pythium ultimum* Trow: C, stalked antheridium that occurs rarely; D, common type of antheridium and oogonium; E, sporangia. F–G, *Pythium de Baryanum* Hesse: F, antheridia and oogonia; G, sporangium. H–O, *Pythium vexans* de Bary: H, I, J, K, L, oogonia and antheridia; M, N, and O, sporangia; K, L, and M are of a strain of the fungus from lemon rootlets and differ somewhat from other forms in having a coiled antheridial branch and irregular-shaped sporangia. P–R, *Pythium rostratum* Butler: P and Q, antheridia and oogonia; R, sporangia.

SUMMARY

Cultures were made from fibrous dead roots of orange and lemon trees growing in various localities in southern California and showing a dying-back, or decline.

Pythium ultimum, *Pythium de Baryanum*, *Pythium vexans*, *Pythium rostratum*, *Phytophthora citrophthora*, and *Phytophthora parasitica* were found on some of these roots, *Pythium ultimum* being the most frequent. The occurrence of the last-named fungus was very infrequent, however, in comparison with that of the nonpythiaceous fungus *Fusarium Solani*, which was found on almost every root.

The results of inoculation tests on orange and lemon fruits with the aforementioned *Pythium* species, with *Pythium irregulare*, and with all the *Phytophthora* species that have been isolated from citrus, namely, *Phytophthora citrophthora*, *Phytophthora parasitica*, *Phytophthora palmivora*, *Phytophthora Syringae*, *Phytophthora cactorum*, *Phytophthora Cinnamomi*, and *Phytophthora megasperma* are reported in this paper.

The distribution of the *Phytophthora* species and descriptions of the morphological characters of the *Phytophthora* and *Pythium* species which have been recorded on citrus are given.

ACKNOWLEDGMENT

The writer wishes to thank Dr. H. S. Fawcett for his suggestions and for the interest which he took in this work during the year that the writer spent at the University of California Citrus Experiment Station.

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THE SUSCEPTIBILITY OF PERENNIAL
DELPHINIUMS TO SIX VIRUSES¹HENRY H. P. SEVERIN²

PERENNIAL DELPHINIUMS (hybrid and horticultural varieties of several species of *Delphinium*) have been found to be naturally infected with several virus diseases. Three such diseases—California aster yellows, celery calico, and delphinium ringspot—have been reported in previous papers (5, 6, 7).³ A fourth—tomato spotted wilt—is reported in this paper. Also, included herein are the results of experimental infection of delphiniums with five other viruses—common cucumber mosaic,⁴ western cucumber mosaic, tobacco ringspot, ordinary tobacco mosaic, and curly top. None of these five has been found on delphinium in California under natural conditions up to the present time, but the first has been reported by other investigators to occur naturally on this host plant in England.

TOMATO SPOTTED WILT

Spotted wilt on perennial delphinium has been reported in California by Gardner, Tompkins, and Whipple (2). Smith (8, 9) reported that considerable damage may be caused to delphinium by the spotted-wilt virus in England and he described the symptoms of the disease as follows: black rings, or numerous double concentric rings, or patches of dead tissue appear on the older leaves. The younger leaves are malformed with edges yellow, necrotic, and inwardly curled. Necrotic patches may develop on the stems and older leaves.

Spotted wilt ranks next to aster yellows (6) in seriousness as a disease of delphinium in the coastal regions of California. Entire fields of delphiniums have been observed to be infected with spotted wilt near San Leandro, San Bruno, and Berkeley.

¹ Received for publication June 24, 1941.

² Associate Entomologist in the Experiment Station.

³ Italic figures in parentheses refer to "Literature Cited" at the end of this paper.

⁴ Common-cucumber-mosaic, tobacco-ringspot, and ordinary-tobacco-mosaic viruses were kindly sent to me by James Johnson, University of Wisconsin.

Numerous efforts have been made to infect experimentally by mechanical inoculation (4) varieties of delphinium seedlings and two-year-old delphiniums with the spotted-wilt virus; but all attempts using naturally infected tomatoes, garden nasturtium (*Tropaeolum majus*), and bull mallow (*Malva nicaensis*) as a source of virus were failures. On the other hand, when the virus extract from calla (*Zantedeschia aethiopica*) was inoculated in delphiniums, infections were occasionally obtained.

The early symptoms of spotted wilt on delphinium are variable and are often difficult to distinguish from delphinium calico, but the late symptoms of the disease are constant and reliable. The first symptom that appears on the leaves of experimentally infected delphiniums is pale green, circular, elliptical, or irregular areas (plate 1, *A*), which later may become surrounded by chlorotic rings (plate 1, *B*). Some leaves may show numerous, double, concentric rings of various sizes, each composed of an outer green and inner chlorotic ring (plate 1, *C*) or a chlorotic ring (plate 1, *D*) surrounding a green center. Sometimes both rings are so small that the inner ring encloses a pinpoint green center. Large lemon-yellow blotches with or without rings sometimes extend into the lobes of the leaves or pale-green areas are embedded in the yellow tissue. Sometimes within the yellow areas, green or chlorotic banding of the veins occurs (plate 1, *E*). The margin of the leaves may be lemon yellow, and often irregular, chlorotic areas extend toward the base of the lobes (plate 1, *F*).

In the later stages of the disease, black rings of various sizes, often irregular in shape, surround chlorotic tissue (plate 2, *A*) which later becomes black on the lower leaves (plate 2, *B*). Black patches often spread over most of the lobes of the leaves (plate 2, *C, D*), and the petioles and veins may become necrotic (plate 2, *E*). The lower leaves turn brown and become dry (plate 2, *F*) with the blackened areas still conspicuous. As the disease progresses, the intermediate and upper leaves develop the ring, the chlorotic, and later the black pattern. The flowers on infected plants were normal.

During the early spring the ring, the chlorotic, and the black patterns appeared on the lower leaves of the new shoots after attaining a height of from 1 to 2 feet and progressively on the intermediate and upper leaves. After the old stock was cut off, the successive symptoms of the disease again appeared on the new shoots during the summer. No symptoms appeared on the leaves of marked infected delphiniums during the past mild winter (1941-42). These observations were made on two- and three-year-old Pacific-strain delphiniums grown in my home garden during 1939 to 1941.

Numerous attempts have been made to recover the spotted-wilt virus from naturally infected delphiniums and transfer it by mechanical inoculation to healthy delphiniums, Marglobe tomatoes, *Nicotiana glutinosa*, Turkish tobacco, Jimsonweed (*Datura Stramonium*) and asters, without results. If the onion thrips (*Thrips tabaci* Lindeman) or *Frankliniella occidentalis* (Perg.) had been used as vectors of the virus, instead of mechanical inoculation, the virus might have been recovered from naturally infected delphiniums.

Celery calico (5) was sometimes recovered from delphiniums infected with spotted wilt.

COMMON CUCUMBER MOSAIC

On Delphiniums.—According to Smith (8, 9), delphinium is very susceptible to and frequently infected with cucumber-mosaic virus in England; he describes the symptoms as follows: "Affected plants present a yellowish (chlorotic) appearance and there are pale areas on the leaves following the veins. A rather faint green mosaic mottle is usually present. As a rule diseased plants are stunted in comparison with healthy plants and the flowers are poor and few in number."

In perennial delphiniums grown from seeds and experimentally infected with common cucumber mosaic by mechanical inoculation (4), a considerable amount of variation occurred in the development of symptoms of the disease in different varieties and hybrids, and even in different plants of the same variety or hybrid. The first symptom which frequently appeared on some of the younger leaves was circular, chlorotic areas (plate 3, A), sometimes distributed along the veins (plate 4, A), which coalesced and formed pale-yellow vein banding (plate 4, B), and later chlorosis sometimes spread in all of the lobes of the leaf (plate 4, C, D). A common symptom on some of the lower leaves was green spotting in the chlorotic areas in one or more lobes of a leaf (plate 3, C). Green vein banding occurred on some leaves of an infected plant (plate 3, E). Sometimes a faint mottling or mosaic pattern (plate 4, E) appeared on one or more leaves of a plant. The symptoms described were infrequently accompanied with crinkling, puckering, and distortion (plate 4, F). Green blisterlike elevations, which are a common symptom of cucumber mosaic on many host plants, were rare on the leaves of infected delphiniums (plate 4, F). The prevailing discoloration, if it occurred, was lemon yellow; but in some delphinium varieties or hybrids, the margin of the leaf was orange, fading to pale yellow within the lobes. All delphiniums observed were kept until the blossoming period; but, without exception, the flowers were normal.

TABLE 1

LIST OF DELPHINIUM VARIETIES AND HYBRID SEEDLINGS EXPERIMENTALLY INFECTED
WITH COMMON CUCUMBER MOSAIC, INCUBATION PERIOD OF
DISEASE, AND RECOVERY OF VIRUS

Delphinium variety or hybrid and date inoculated (1939-40)	Del- phiniums inoculated	Del- phiniums infected	Incubation period of disease in plants		Recovery of virus from infected delphiniums	
			Range	Mean	Cucumbers inoculated	Cucumbers infected
	number	number	days	days	number	number
Blackmore and Langdon hybrids:						
October 31.....	5	2	28-55	41.5	10	0
Belladonna tall hybrids:						
July 9.....	5	1	7		5	0
August 14.....	5	3	43-57	47.7	15	15
Chinese Azure Blue:						
August 31.....	5	1	40	.....	5	0
Clivenden Beauty:						
July 8.....	5	2	6-22	11.0	10	0
September 17.....	5	2	54-54	54.0	10	10
<i>Delphinium Parryi</i> var. <i>maritimum</i> :						
November 15.....	2	1	*	*	5	1
Dreer's De Luxe Art shades:						
July 9.....	5	1	9	.....	5	1
Dreer's De Luxe Dark-Blue shades:						
July 9.....	5	1	8	.....	5	2
September 17.....	2	2	45-54	49.5	10	10
Dreer's De Luxe Light-Blue shades:						
July 9.....	1	1	*	*	5	5
August 31.....	4	3	25-26	25.7	15	0
English hybrids Deep-Blue shades:						
July 9.....	5	1	22	.....	5	5
Burpee's Floradale Giants Deep Blue:						
July 9.....	1	1	*	*	5	4
August 31.....	5	1	40	.....	5	0
Burpee's Floradale Giants Light Blue:						
July 9.....	1	1	*	*	5	5
Burpee's Floradale Giants Mid Blue:						
July 9.....	3	2	22-24	.....	10	5
August 31.....	2	2	38-38	38.0	10	10
September 17.....	1	1	34	.....	5	5
A. & M. Gold Medal hybrid:						
July 8.....	4	2	7-10	8.5	10	10
Gold Medal hybrids:						
September 17.....	1	1	55	.....	5	5
Hardy larkspur (<i>Delphinium formosum</i>):						
September 17.....	5	2	27-53	45.0	10	10
Iceberg:						
August 31.....	5	2	25-26	25.5	10	4
September 17.....	1	1	24	.....	5	5
Lemon Gem:						
July 9.....	3	3	*	*	15	15
Burpee's Mammoth hybrids:						
July 9.....	5	2	6-7	6.5	10	0
Pacific Giant mixed:						
July 9.....	5	2	6-20	13.0	10	0
September 17.....	1	1	38	.....	5	5
Pacific Giant White:						
July 8.....	5	5	*	*	25	25
A. & M. Sunbeam hybrids:						
July 9.....	4	4	5-24	11.2	20	12
Total.....	108	54	.....	.....	270	189
Percentage.....	.....	50.9	.....	.....	.....	68.9

* No symptoms, but virus recovered from infected delphinium

The type of infection was systemic. The symptoms sometimes appeared on the inoculated leaves of delphinium seedlings, or on a few of the intermediate or upper leaves not inoculated. The virus was recovered and transferred to White Spine cucumber plants, from the inoculated leaves, and also from the intermediate and upper leaves not inoculated.

The delphinium varieties experimentally infected with the virus are listed in table 1. Of a total of 106 delphinium seedlings inoculated, 54, or 50.9 per cent, were infected. The virus was recovered from 39 of 54 infected delphiniums, or 72.2 per cent; the infected plants included 12 symptomless carriers.

On Cucumbers.—The first symptom of common cucumber mosaic on the cotyledons of White Spine cucumber seedlings is chlorotic rings, each enclosing a green area. Sometimes an outer chlorotic ring and an inner green ring surround a chlorotic area. Later the green area becomes chlorotic and a pinpoint necrotic center appears. Cleared veinlets develop on the first leaf when small (plate 5, *A*), later numerous rings appear similar to those on the cotyledons but much smaller. The blade is often cupped inward along the midrib, or the margin is rolled outward and the petiole bent downward (plate 5, *B*). The second leaf is sometimes balled (plate 5, *B*). Blisterlike elevations develop on some of the younger leaves. In a later stage, chlorosis begins at the margin of the first leaf and sometimes progresses until the entire blade becomes yellow. The older leaves are mottled with yellow or orange and green areas. Necrotic streaks which crack later appear on the stem and on some of the petioles, and finally the stem may collapse and the plant die.

WESTERN CUCUMBER MOSAIC

The present known distribution of western cucumber mosaic is in the interior regions of California; the disease is common in the Sacramento and San Joaquin valleys, but no infected host plants have been found in the coastal regions of the San Francisco Bay district, Santa Clara Valley, or in the fog belt of the Salinas Valley. The host range, property studies, and vectors of this virus are the subjects of a separate study.

Since western-cucumber-mosaic virus produces fern leaf, filiform leaf, or shoestring leaf on tomato and other host plants, an examination was made of a large number of delphiniums in the central-coastal district that had such malformed leaves (fig. 1) and dwarfed and frequently brown and dried flowers (fig. 2, *A*, *B*). All attempts to recover from these delphiniums a virus producing such symptoms on tomato and other host plants were failures. California-aster-yellows and celery-calico viruses were recovered from delphiniums with malformed leaves and

abnormal flowers, but these viruses do not produce such symptoms on delphinium. No intensive investigation of western cucumber mosaic on delphinium in the interior regions of California has been made.

In perennial delphiniums grown from seeds experimentally infected with western cucumber mosaic by mechanical inoculation (4), the symp-

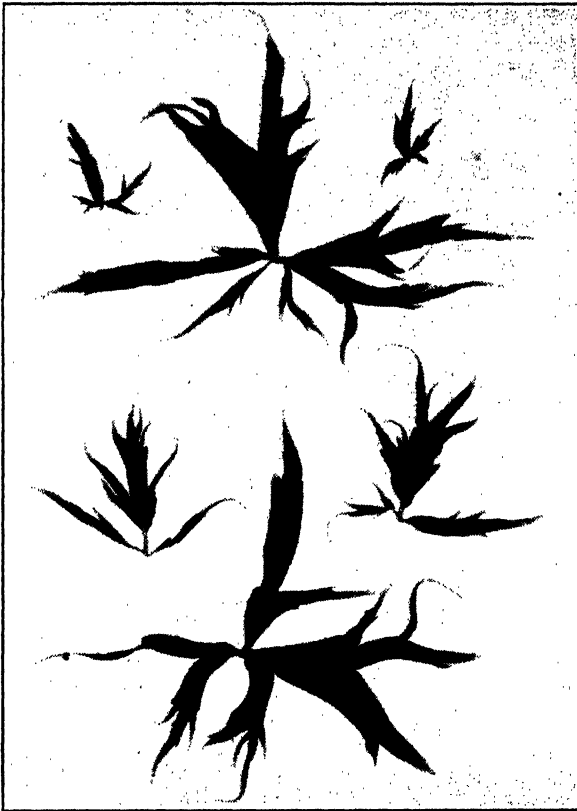


Fig. 1.—Malformed leaves resembling fern leaf, filiform leaf, or shoestring leaf (cause unknown) on Dreer's De Luxe delphinium. The virus of celery calico was recovered from this plant and transferred to cucumbers and Turkish tobacco, but this virus does not produce the symptom. (Mt. Eden, December 22, 1938.)

toms on the leaves are somewhat milder than those of common cucumber mosaic. They are usually not conspicuous and may be limited to one or more inoculated leaves or to a few of the intermediate or upper leaves not inoculated. Some infected delphinium varieties or hybrids show a pale, yellow discoloration of a few leaves. Plate 3 shows a comparison of some of the symptoms caused by common and by western cucumber mosaic:

circular or elongated, chlorotic areas are illustrated in *A, B*; green spotting in chlorotic areas in *C, D*; and green vein banding in *E, F*. The flowers were normal with both viruses.

The type of infection was systemic as determined by the development of symptoms of the disease and recovery of the virus as described for common cucumber mosaic.



Fig. 2.—Spikes of Dreer's De Luxe delphinium showing fern leaf, filiform leaf, or shoestring leaf (cause unknown): *A*, spike showing dwarfed flowers and seed pods; *B*, spike showing brown and dried flowers. (Mt. Eden, December 27, 1938.)

The delphinium varieties and hybrids experimentally infected with the virus are listed in table 2. Of a total of 197 delphiniums inoculated, 127, or 64.0 per cent, were infected. The virus was recovered from 125 of 127 infected delphiniums, or 98.4 per cent; the infected plants included 75 symptomless carriers.

The incubation period of the disease varied from 6 to 55 days, as shown in table 2.

The virus was recovered from experimentally infected delphiniums

TABLE 2

LIST OF DELPHINIUM VARIETIES AND HYBRID SEEDLINGS EXPERIMENTALLY INFECTED
WITH WESTERN CUCUMBER MOSAIC, INCUBATION PERIOD OF
DISEASE, AND RECOVERY OF VIRUS

Delphinium variety or hybrid and date inoculated (1939-40)	Del- phiniums inoc- ulated	Del- phiniums infected	Incubation period of disease in plants		Recovery of virus from infected delphiniums	
			Range	Mean	Cucumbers inoculated	Cucumbers infected
	number	number	days	days	number	number
Blackmore and Langdon Giants:						
June 28.....	1	1	15	....	5	0
January 16.....	3	3	—*	—*	15	15
Belladonna tall hybrids:						
June 28.....	5	1	13	....	5	0
Chinese Azuro Blue:						
July 8.....	3	3	—*	—*	15	15
Chinese Dark Blue:						
June 25.....	5	1	19	....	5	5
December 20.....	3	3	—*	—*	15	9
October 1.....	1	1	—*	—*	5	5
December 20.....	3	1	—*	—*	5	3
Clivenden Beauty:						
November 20.....	5	5	—*	—*	25	25
A. & M. Clivenden Beauty:						
June 25.....	5	4	11-12	11.5	20	20
<i>Delphinium cardinale</i> :						
June 2.....	3	3	—*	—*	15	9
<i>Delphinium grandiflorum</i> var. <i>album</i> :						
June 25.....	5	3	19-34	24.0	15	15
<i>Delphinium Zazil</i> :						
March 14.....	1	1	—*	—*	5	5
Dreer's De Luxe Art shades:						
June 28.....	5	4	8-17	14.0	20	20
Dreer's De Luxe Dark-Blue shades:						
June 28.....	5	2	14-16	15.0	10	10
November 19.....	4	4	—*	—*	20	20
Dreer's De Luxe Light-Blue shades:						
July 8.....	1	1	—*	—*	5	1
Dreer's De Luxe Mid-Blue shades:						
June 28.....	5	3	8-15	11.0	15	15
November 19.....	5	1	—*	—*	5	5
Dwarf Chinese Blue Butterfly:						
June 28.....	5	2	15-39	27.0	10	10
English Hybrids Deep-Blue shades:						
June 28.....	5	1	14	....	5	4
English Hybrids Light-Blue shades:						
July 8.....	1	1	9	....	5	2
English Hybrids Mid-Blue shades:						
June 25.....	5	3	18-20	19.0	15	15
November 19.....	5	1	—*	—*	5	5
English Hybrids Pastel shades:						
July 8.....	2	2	—*	—*	10	10
August 31.....	5	1	55	....	5	5
Burpee's Floradale Giants Deep Blue:						
July 8.....	1	1	—*	—*	5	5
Carried forward.....	97	57	....	....	285	253

* No symptoms, but virus recovered from infected delphiniums.

TABLE 2—*Concluded*

Delphinium variety or hybrid and date inoculated (1939-40)	Delphiniums inoculated	Delphiniums infected	Incubation period of disease in plants		Recovery of virus from infected delphiniums	
			Range	Mean	Cucumbers inoculated	Cucumbers infected
	number	number	days	days	number	number
<i>Brought forward</i>	97	67	....	....	285	253
Burpee's Floradale Giants Light Blue:						
July 8.....	2	2	—* ..*	....	10	2
August 31.....	1	1	35	...	5	5
Burpee's Floradale Giants Mid Blue:						
August 31.....	5	3	35-35	35 0	15	15
Giant Single and Double hybrids:						
July 8.....	4	4	—* ..*	....	20	8
A. & M. Gold Medal hybrids:						
June 25.....	5	2	15-19	17.0	10	10
Gold Medal hybrids:						
July 8.....	3	3	...*	—*	15	15
Hardy larkspur (<i>Delphinium formosum</i>):						
June 25.....	5	4	11-11	11 0	20	20
October 1.....	5	5	—*	—*	25	25
Hybrids mixed:						
June 25.....	5	4	11-22	16 2	20	20
November 20.....	5	4	—*	—*	20	20
Iceberg:						
June 28.....	5	1	9	....	5	5
August 31.....	5	3	35-35	35.0	15	15
Improved Belladonna:						
November 19.....	5	5	—*	—*	25	16
Improved English hybrids mixed:						
July 8.....	1	1	...*	—*	5	5
Lady Guinevere:						
November 20.....	5	5	...*	—*	25	25
Lemon Gem:						
November 20.....	5	5	—*	—*	25	25
Burpee's Mammoth hybrids:						
July 8.....	4	1	6	...	5	5
July 8.....	2	2	—*	—*	10	10
October 1.....	1	1	—*	—*	5	5
New Hollyhock strain:						
November 20.....	5	5	—*	—*	25	25
Pacific Giant mixed:						
June 28.....	5	3	15-17	12.3	15	9
Pacific Giant White:						
June 25.....	5	2	15-18	16.5	10	10
A. & M. Sunbeam hybrids:						
July 8.....	5	1	7	....	5	5
July 8.....	2	2	—*	—*	10	8
Wrexham Hollyhock strain:						
October 1.....	5	1	—*	—*	5	5
Total.....	197	127	....	....	665	550
Percentage.....	....	64.0	....	....	...	82.7

* No symptoms, but virus recovered from infected delphiniums.

and transferred to White Spine cucumber by mechanical inoculation. The first symptom of western cucumber mosaic on the cotyledons of cucumber seedlings is chlorotic rings, each surrounding a green area, which later becomes necrotic. The first leaf is often cupped inward along the midrib and with the margin rolled inward, but later the blade may expand normally. Numerous, small, circular, chlorotic areas appear on the first leaf (plate 5, *C*) and these coalesce later (plate 5, *D*). Necrosis of the circular, chlorotic areas may occur about 1 month after inoculation. Some of the younger leaves may show blisterlike elevations. The older leaves are sometimes malformed and become mottled with yellow and green areas. No necrosis of the stem and petioles occurs, western cucumber mosaic differing in this respect from ordinary cucumber mosaic.

TOBACCO RINGSPOT

Wingard (10) experimentally infected 62 species of plants belonging to 38 genera in 17 families with tobacco-ringspot virus but made no attempt to infect any species of the family Ranunculaceae, to which delphinium belongs.

Twenty-five perennial delphinium seedlings were mechanically inoculated (4) with tobacco-ringspot virus, and 4 plants developed symptoms of the disease. Five Pacific-strain two-year-old delphiniums were inoculated and reinoculated with the virus but failed to show symptoms.

The ringspots were composed of alternating, concentric, chlorotic and green rings surrounding green or chlorotic tissue in the center (plate 6, *A*). The ringspots varied considerably in number and size on the leaves (plate 6, *B*).

The type of infection was systemic. On delphinium seedlings, ringspots appeared on the newly developing basal leaves that were not inoculated and on the lower leaves of the stalk but appeared only faintly on the intermediate leaves and finally failed to appear on the upper or younger leaves.

The virus was recovered from delphinium leaves showing ringspots and from the upper leaves not showing symptoms when the expressed juice was inoculated in White Spine cucumbers. The first symptom of tobacco ringspot on the cotyledons of cucumber seedlings is numerous, pale, chlorotic rings, each enclosing a green area. The green area gradually becomes smaller, the chlorotic ring widens, until the entire circular area becomes chlorotic. A pinpoint necrotic center appears in the chlorotic area and later enlarges until the entire circular area becomes necrotic.

The sequence of symptoms on the first leaf is somewhat similar to

that on the cotyledons. The chlorotic rings surrounding green areas are smaller and more numerous (plate 5, *E*) than on the cotyledons. Frequently the chlorotic areas are bounded by cleared veinlets (plate 5, *E*). In the later stage a chlorotic ring surrounds necrotic tissue (plate 5, *F*), which sometimes drops out, leaving a hole.

The second leaf is usually cupped inward along the midrib, with rolled margin, and the blade becomes puckered with circular chlorotic areas.

ORDINARY TOBACCO MOSAIC

Grant (3) infected an annual larkspur (*Delphinium Consolida*) with the tobacco-mosaic virus; the symptom expression was stunting of the plants, mottling, yellowing, and necrosis. The type of infection was systemic.

Blackmore and Langdon and Pacific-strain perennial delphiniums experimentally infected with tobacco mosaic by mechanical inoculation (4) frequently showed brown necrotic streaks along the veins of the inoculated leaves (plate 6, *C*) and large intervenal necrotic areas (plate 6, *D*), followed by yellowing and drying of the leaves.

The type of infection was local and not systemic. In twenty-five delphinium seedlings inoculated with the tobacco-mosaic virus, symptoms of the disease developed only on the inoculated leaves. The virus was recovered and transferred to *Nicotiana glutinosa* from the inoculated leaves but not from the newly developing leaves. In another experiment two-year-old Pacific-strain delphiniums were inoculated with the ordinary-tobacco-mosaic virus, a few of the upper or youngest, the intermediate, and the lowest or basal leaves being inoculated on each plant. The inoculated leaves were marked by cutting off the tip of a lobe. The virus was recovered 17 days after inoculation only from the inoculated leaves. The flowers were normal.

The virus was recovered from infected leaves of delphiniums and transferred to *Nicotiana glutinosa*, which developed local lesions (plate 6, *E*); these coalesced to form necrotic areas (plate 6, *F*), and later the inoculated leaves became dry.

CURLY TOP

Orange larkspur (*Delphinium nudicaule*), a native perennial delphinium occurring in California and Oregon, has been experimentally infected with curly top, and the virus was recovered and transferred to healthy sugar beets by previously noninfective beet leafhoppers with the method described by Freitag and Severin (1). Orange larkspur infected

with curly top failed to develop symptoms of the disease under greenhouse conditions.

During the past ten years, inquiries have been received from scientists, seed companies, nurserymen, and growers of delphinium in home gardens, as to whether the virus of curly top transmitted by the beet leafhopper, *Eutettix tenellus* (Baker) causes phyllody and virescence or greening of the flowers in delphinium. An attempt was made to infect one variety of delphinium with the virus of curly top by means of infective male beet leafhoppers. Five healthy Wrexham delphiniums grown from seeds were each exposed to lots of 20 infective leafhoppers. When one lot of insects died, another lot of 20 males was put in the cage, each plant being inoculated with from 2 to 4 lots of leafhoppers. Wrexham delphinium was an unfavorable food plant for the beet leafhopper; the males lived from 4 to 8 days on the seedlings. The five delphiniums were kept under observation for a period of 7 months, but no symptoms developed; and repeated efforts to recover the curly-top virus were failures. It is evident that Wrexham delphinium is immune to the virus of curly top.

During the following spring, five Wrexham delphiniums used as check or control plants were inoculated with the aster-yellows virus by the geminate leafhopper and typical symptoms of this disease developed.

SUMMARY

Perennial delphinium has been proved to be infected with tomato spotted wilt in nature. This disease ranks next to aster yellows as a serious disease in the central-coastal regions of California. Delphinium has been demonstrated to be naturally infected with a virus complex including spotted wilt and celery calico.

Varieties and hybrid delphiniums have been experimentally infected with common cucumber mosaic and western cucumber mosaic. The type of infection was systemic.

Delphiniums were experimentally infected with tobacco ringspot and ordinary tobacco mosaic. The type of infection was systemic with tobacco ringspot and local with ordinary tobacco mosaic.

Orange larkspur (*Delphinium nudicaule*), a native perennial delphinium, has been reported in a previous paper (1) to be a symptomless carrier of curly top. Wrexham delphinium was immune to the virus of curly top.

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PLATES

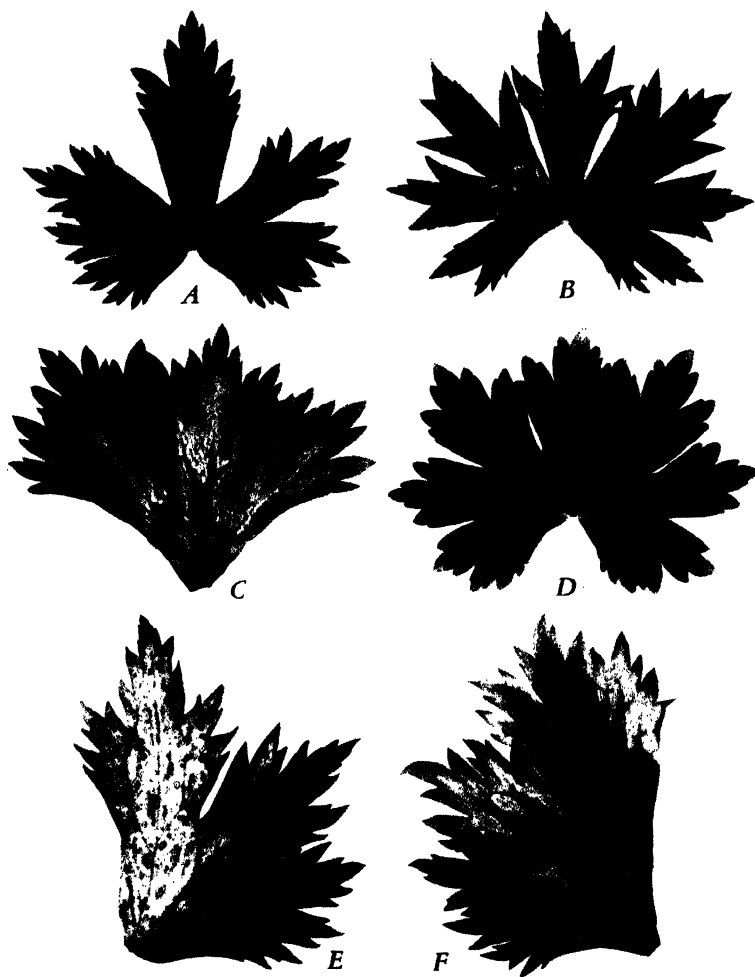


Plate 1. —Early stages of spotted wilt on leaves of delphiniums: *A*, pale-green areas, the first symptom of the disease; *B*, chlorotic rings surrounding green areas and broken, yellow bands along the margin; *C*, green or chlorotic banding of the veins and veinlets; *D*, *E*, double concentric rings of various sizes, each composed of an outer green and inner chlorotic ring, or a chlorotic ring encircling a green center; *F*, lemon-yellow discolorations along the margin and irregular, chlorotic areas.

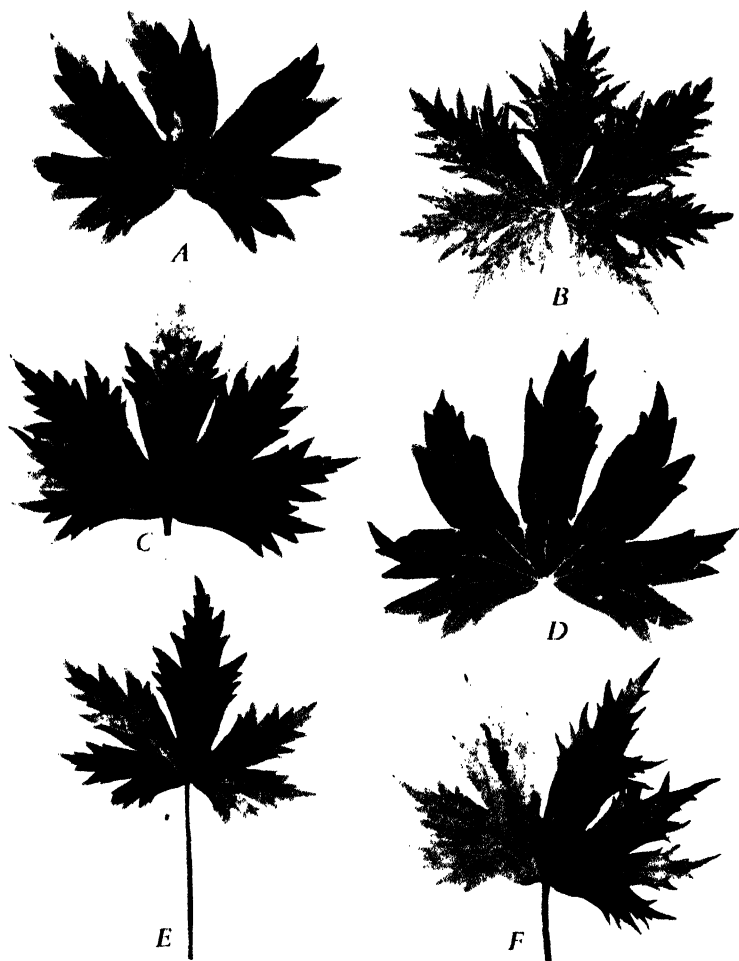


Plate 2.-- Late stages of spotted wilt on leaves of delphinium: *A*, black, irregular areas bounding chlorotic tissue; *B*, small pinpoint and large circular or irregular areas which frequently coalesce; *C*, *D*, black areas spreading in lobes; *E*, black region surrounding a ring that encloses a chlorotic center, and necrosis of veins and petioles; *F*, left lobes turning brown and becoming dry, and black areas on other lobes.



Plate 3.—Comparison of symptoms on the leaves of delphinium infected with common cucumber mosaic (A, C, E) and with western cucumber mosaic (B, D, F): A, B, circular or elongated, chlorotic areas; C, D, green spotting in chlorotic areas; E, F, green vein banding.

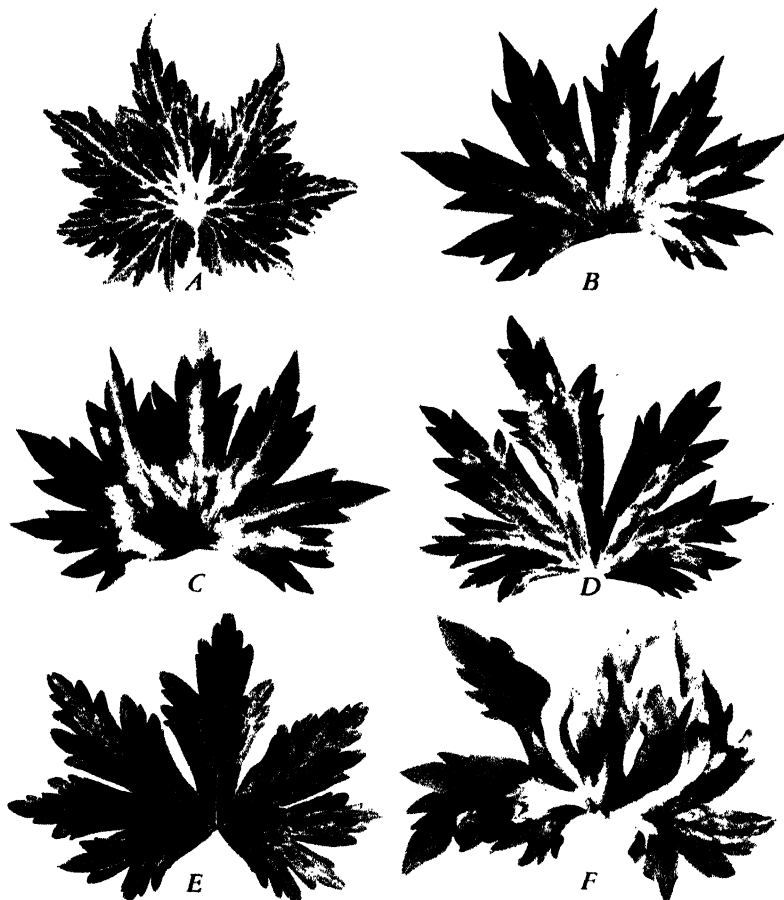


Plate 4.—Common-cucumber-mosaic symptoms on leaves of delphiniums: *A*, circular chlorotic areas distributed along the veins; *B*, pale-yellow vein banding; *C*, *D*, chlorosis spreading in all lobes; *E*, faint mottling or mosaic pattern; *F*, distortion, chlorosis, and blisterlike elevations.

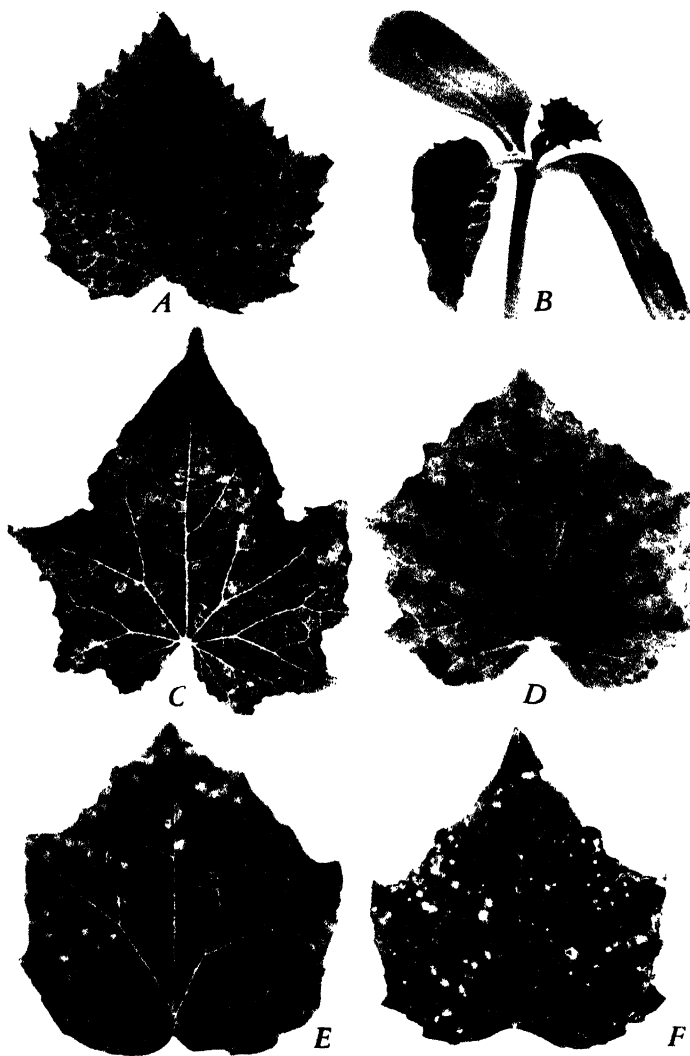


Plate 5.—Symptoms on leaves of White Spine cucumber (*Cucumis sativus*) produced by three viruses recovered from infected delphiniums: A, B, from seedlings infected with common cucumber mosaic, A showing cleared veinlets, and B, drooping of petiole and rolled margin of the first leaf and the balled second leaf; C, D, from plants infected with western cucumber mosaic, C showing small, circular, chlorotic areas on the first leaf, and D, chlorotic and green tissue forming a mottling; E, F, from plants infected with tobacco ringspot, E showing numerous, small, chlorotic areas, some bounded by cleared veinlets, and F, chlorotic rings with necrotic centers.



Plate 6.—*A, B*, Tobacco-ringspot symptoms on the leaves of delphinium seedlings: *A*, ringspots 5 weeks after inoculation, consisting of alternating concentric, chlorotic, and green rings surrounding either green or chlorotic tissue in the center; *B*, ringspots 8 weeks after inoculation, showing variation in size. *C, D*, Symptoms of ordinary tobacco mosaic on leaves of delphinium seedlings; *C*, brown necrotic streaks frequently on the veins of the inoculated leaf; *D*, interval, necrotic areas. *E, F*, Leaves of *Nicotiana glutinosa*: *E*, local lesions of ordinary tobacco-mosaic virus which was recovered from infected delphiniums; *F*, local lesions coalescing to form necrotic areas.

LEAF VARIEGATIONS OF PERENNIAL DELPHINIUMS

HENRY H. P. SEVERIN

LEAF VARIEGATIONS OF PERENNIAL DELPHINIUMS¹

HENRY H. P. SEVERIN²

LEAF VARIEGATIONS and variegations in flowers are not uncommon among ornamental flowering plants. In perennial delphiniums two types of leaf variegations, for which the names "golden-leaf" and "silver-leaf" variegations are proposed, have been observed in seedbeds, in cold frames covered with muslin, in commercial fields of delphiniums grown for seed production and for the cut-flower trade, in nurseries, and in home gardens.

Reichert (11)³ lists among diseases of ornamental plants in Palestine a nonparasitic yellow-leaf discoloration of *Delphinium* sp.

A leaf variegation somewhat similar to the leaf variegations of delphinium has become serious in certain strawberry varieties, affecting 25 to 50 per cent or all of the plants. The disease has been called "strawberry mosaic" (1), "suspected strawberry mosaic" (2, 8), "noninfectious chlorosis" (4), "June yellows" (11), "yellows" (9, 10), and "gold leaf" (8); and at present the accepted name is "leaf variegation" (3, 5, 6, 7, 12).

Berkeley (1), Guba (8), Plakidas (11), and Demaree and Darrow (7) failed to transmit leaf variegation in strawberries by insects, sap inoculations, and grafting of diseased and healthy runners, and thus presented conclusive evidence that the disease is noninfectious and not caused by a virus.

Berkeley (2) was first to suggest that leaf variegation in strawberries was of genetic origin. Clark (4) expressed the opinion that the disease was caused by a gene mutation and was hereditary. The evidence as a result of breeding work, according to Demaree and Darrow (7), suggests a sporting or mutation, which has been considered in most instances as the appearance of a recessive character in somatic tissue; they state: "Evidence so far indicates that leaf variegation is not due to a single gene. Even if by selfing no yellow plants appear, this is by no means evidence that a complimentary gene for yellowing may not be in the variety."

In the investigation of leaf variegations on perennial delphinium, the patterns on seedlings and plants growing in the field were studied; attempts were made to reproduce the variegations on delphinium seedlings

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³ Italic figures in parentheses refer to "Literature Cited" at the end of this paper.

by mechanical inoculation and by means of different species of aphids. Virus diseases in leaf-variegated plants were studied; and transmission of leaf variegations through the seeds was tested.

DESCRIPTION OF LEAF VARIEGATIONS

Golden-Leaf Variegation.—The patterns of golden-leaf variegation resemble those of calico on second-year or older delphiniums, but the two troubles can readily be distinguished in the field. Golden-leaf variegation affects all of the leaves on a plant, including the upper or apical leaves on the stalks (plate 2, *A, B*). The symptoms of calico are confined to the basal and intermediate leaves; the upper or apical leaves on the stalks remain green. The line and ring patterns characteristic of calico on the leaves of seedlings and perennial delphiniums described in one of the preceding papers (15) have never been observed on plants affected with golden-leaf variegation.

The most prominent and characteristic pattern of golden-leaf variegation on perennial delphiniums is the large yellow areas which extend into the lobes or divisions of the leaves (plate 1, *A*; plate 2, *A*). When the spike and all of the leaves are cut off and the plants are given a rest period during the winter, the new leaves on the shoots may show faint, pale-yellow streaks which gradually enlarge (plate 1, *B*) or the larger golden-yellow or pale-yellow and green areas appear immediately instead of developing from the streaks. The early stages of leaf variegation on some plants may show yellow streaks (plate 1, *C*). Later the leaves lose more and more of their green color and become mottled with yellow and green (plate 1, *D, E*). The patterns vary considerably on perennial delphiniums; some show mostly streaking of the leaves (plate 2, *B*); others chiefly mottling, or a combination of both; or mostly large golden-yellow and green areas. The flowers appear normal on perennial delphiniums showing golden-leaf variegations.

Golden-leaf variegation seems to be of a systemic nature, since the new shoots which develop from the roots after a rest period show symptoms on all leaves.

Silver-Leaf Variegation.—The appearance of silver-leaf variegation is similar to the patterns of golden-leaf type except that grayish white instead of golden-yellow areas occur on the lobes or divisions of the leaves (fig. 1). Frequently delphinium seedlings show grayish-white areas with numerous, small, green dots (plate 2, *C*), and sometimes the lobes of a leaf from the same plant are nearly albino with chains of dots extending along the veins (plate 2, *D*). The silver-leaf variegations are frequently found in seedbeds but are rarely found on perennial delphiniums grow-

ing in the field. Seedlings showing silver-leaf variegations were transplanted from seedbeds in pots and were kept under observation in a glasshouse. A few of the seedlings later developed the golden-leaf patterns, but others retained the silver-leaf patterns. A delphinium plant was found near Salinas with golden-leaf variegation confined to the



Fig. 1.—Delphinium leaf showing silver-leaf variegation with white or gray areas on the lobes.

basal and intermediate leaves and silver-leaf variegation to the upper leaves. Further investigations are necessary to determine whether the two types of leaf variegations are identical.

MECHANICAL INOCULATION

All attempts to transmit the causal agent of golden-leaf or silver-leaf variegation from 25 delphiniums by sap inoculation with the carborundum method (13) to healthy delphinium seedlings, Turkish tobacco, *Nicotiana glutinosa*, White Spine cucumbers, and celery, were failures.

APHIDS TESTED

The following ten species of aphids failed to transmit the causal agent of golden-leaf or silver-leaf variegations to healthy delphiniums:

Celery leaf aphid, *Aphis apigraveolens* Essig

Celery aphid, *Aphis apti* Theobald

Rusty-banded aphid, *Aphis ferruginea-striata* Essig
Cotton, or melon, aphid, *Aphis gossypii* Glover
Erigeron root aphid, *Aphis middletonii* Thomas
Yellow willow aphid, *Cavariella capreae* (Fabricius)
Lily aphid, *Myzus circumflexus* (Buckton)
Foxglove aphid, *Myzus convolvuli* (Kaltenbach)
Green peach aphid, *Myzus persicae* (Sulzer)
Honeysuckle aphid, *Rhopalosiphum melliferum* (Hottes)

LEAF VARIEGATION, CALICO, AND ASTER YELLOWS

Delphinium plants may show leaf variegation and also harbor the calico virus. The juice was extracted from the leaves of two Dreer's De Luxe hybrid delphiniums showing golden-leaf variegation and inoculated in delphinium seedlings, Turkish tobacco, White Spine cucumbers, and celery. These host plants developed typical symptoms of calico, but leaf variegation failed to appear on the delphinium seedlings.

It was not uncommon to find delphinium plants under natural conditions showing both golden-leaf variegation and symptoms of aster yellows. The aster-yellows virus was recovered from Dreer's De Luxe hybrid delphiniums showing a combination of aster yellows and leaf variegation by previously noninfective long-winged aster leafhoppers, *Macrostelus divisus* (Uhl.); the mountain leafhopper, *Thamnotettix montanus* Van D.; and the geminate leafhopper, *T. geminatus* Van D.; and was transferred to healthy aster, celery, and delphinium plants; but leaf variegation again failed to appear.

Golden-leaf variegation is sometimes associated with both calico and aster yellows in the same plant under natural conditions. The inoculum from such plants produced symptoms of calico in Turkish tobacco, White Spine cucumber, celery, and delphinium, but not leaf variegation on delphinium seedlings. The aster-yellows virus was recovered by previously noninfective long-winged aster leafhoppers and transferred to healthy asters.

TRANSMISSION IN SEED

Golden-leaf and silver-leaf variegations were found among delphinium seedlings transplanted in cold frames covered with muslin; 1 per cent of the plants developed variegations before transplanting in the field. Many delphinium varieties and hybrids were grown from seeds in cages, and both types of leaf variegations appeared on the seedlings. Seeds were planted from one delphinium plant showing golden-leaf variegation, and all of the 18 seedlings developed this type of variegation. It is evident that the causal agent of leaf variegation is seed-borne.

On the other hand, in second-year Dreer's De Luxe hybrid delphin-

iums grown in the field, as high as 5 per cent of the plants were affected with leaf variegations. It may be possible that some delphinium seedlings develop leaf variegations after being transplanted in the field.

SUMMARY

Golden-leaf and silver-leaf variegations are nontransmissible by juice or insect inoculations and are seed-borne. They are not virus diseases.

ACKNOWLEDGMENTS

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PLATES



Plate 1.—Golden-leaf variegation from perennial delphiniums: *A*, large, yellow areas extending into the lobes or divisions of the leaves; *B*, faint, pale-yellow streaks on a leaf from a new shoot which grew from the roots after all of the leaves and the spike were cut off and the plant was given a rest period during the winter; *C*, yellow streaks; *D*, *E*, yellow and green mottling.



Plate 2.—A, B, Apical ends of delphinium shoots showing golden-leaf variegation; C, D, two leaves from the same delphinium seedling showing silver-leaf variegations, with numerous, small, green dots scattered in the grayish-white lobes or arranged in chains along the veins.

VIROSES OF ANNUAL LARKSPURS

HENRY H. P. SEVERIN

VIROSES OF ANNUAL LARKSPURS¹

HENRY H. P. SEVERIN²

ANNUAL LARKSPURS are naturally infected with many virus diseases, in a few of which the identity of the virus has been determined. Annual and perennial larkspurs, or delphiniums, both belong to the genus *Delphinium*, and hence in connection with investigations of diseases and leaf variegations of perennial species (2, 3, 4, 5, 6)³ a study was undertaken to determine whether delphinium viroses (2, 3, 6) also affect annual species under natural conditions.

In this paper the following virus diseases of annual larkspurs are discussed: California aster yellows, celery calico, curly top, tomato spotted wilt, and western cucumber mosaic.

CALIFORNIA ASTER YELLOWS

Annual larkspur was demonstrated to be naturally infected with California aster yellows. The virus was recovered from naturally infected annual larkspurs grown for the cut-flower trade, in home gardens, and on seed farms. The virus was recovered from naturally infected annual larkspurs and transferred to asters by the short-winged and long-winged forms of aster leafhopper, *Macrosteles divinus* (Uhl.), and was transferred to celery by the mountain leafhopper, *Thamnotettix montanus* Van D., and by the geminate leafhopper, *T. geminatus* Van D.

Since short-winged and long-winged aster leafhoppers were not efficient vectors of the virus to perennial delphiniums and a high mortality occurred within 24 hours, an attempt was made to infect annual larkspurs with these leafhoppers experimentally. Table 1 gives a list of annual larkspurs which were infected with the virus. Both short-winged and long-winged aster leafhoppers infected 19 of the 24 plants inoculated, or 79.2 per cent. The virus was recovered from infected annual larkspurs by these leafhoppers and transferred to asters.

The longevity of short-winged aster leafhoppers on varieties of annual larkspur varied from 9 to 26 days for the males and from 15 to 22 days for the females; that of the long-winged aster leafhoppers varied from 8 to 13 days for the males and from 8 to 21 days for the females. Nymphs of both leafhoppers emerged from eggs deposited in larkspurs but none lived to become adults. The nymphal stages of the mountain and gemi-

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³ Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

nate leafhoppers were completed on the Lilac Supreme, Sky Blue, Daintiness, and Exquisite Pink Improved varieties of annual larkspur.

The first symptom resulting from aster yellows on annual larkspur was a chlorotic appearance of the stem and flower stalk followed by a yellowing of the foliage. Droplets of clear sap sometimes exuded from the petioles and stems of experimentally infected annual larkspurs. Later the droplets turned brown and formed a crust, a symptom which also occurred on naturally infected larkspurs. Phyllody, or the tendency of the floral organs to resemble leafy structures, and virescence, or greening of the flowers, were somewhat similar to those described on perennial delphiniums in a previous paper (2). The sepals, petals, carpels, and stamens were often replaced by green leafy structures (plate 1, *B, F*) or the carpels were leaflike and the stamens were apparently normal (plate 1, *A, E*), and sometimes the carpels were replaced by stems bearing variously modified appendages frequently resembling leaves (plate 1, *C*).

The incubation period of the disease varied from 18 to 62 days, with an average of 36.4 days, as indicated in table 1.

CELERY CALICO

Annual larkspur was proved to be infected with celery calico in nature. The virus was recovered from naturally infected larkspurs and transferred by mechanical inoculation (1) to celery, Turkish tobacco, and White Spine cucumbers.

The varieties of larkspurs experimentally infected by mechanical inoculation are listed in table 2. A total of 108 annual larkspurs were inoculated, and 101, or 93.5 per cent, became infected, as shown in table 2. The virus was recovered and transferred to White Spine cucumber (table 2).

It is often difficult to detect symptoms of calico on the multifid linear segments of the leaves. Small green areas embedded in yellow portions of the leaves (plate 2, *D*) proved to be a reliable symptom of the disease.

CURLY TOP

Annual larkspurs have been demonstrated to be infected with curly top in the San Joaquin Valley. Previously noninfective beet leafhoppers, *Eutettix tenellus* (Baker), after feeding on the naturally infected plants, were transferred to sugar beets, and typical symptoms of the disease developed.

The following varieties of annual larkspurs were experimentally in-

feeted with curly top by means of infective beet leafhoppers: Double mixed, Gloria, Exquisite Pink Improved, Lilac, Pink, and Sky Blue.

The method used to experimentally infect annual larkspurs grown from seeds was to allow 20 infective male beet leafhoppers to feed on

TABLE 1

TRANSMISSION OF CALIFORNIA-ASTER-YELLOW VIRUS BY SHORT-WINGED AND LONG-WINGED ASTER LEAFHOPPERS TO ANNUAL LARKSPURS AND INCUBATION PERIOD OF THE DISEASE

Type and variety of annual larkspur	With short-winged aster leafhopper			With long-winged aster leafhopper			Incubation period of disease in plant, with both insects
	Plants inoculated	Period of inoculation	Plants infected	Plants inoculated	Period of inoculation	Plants infected	
	<i>number</i>	<i>days</i>	<i>number</i>	<i>number</i>	<i>days</i>	<i>number</i>	<i>days</i>
Giant Imperial Double:							
Carmine King.	1	1	0	1	1	1	32
Daintiness.	2	20, 26	2	2	13, 20	1	..
Double mixed.	1	13	1	1	13	1	..
Exquisite Pink Improved	2	10, 15	2	2	2, 8	1	..
Gloria.	2	16, 22	2	2	8, 21	1	..
La France.	1	2	1	1	2	1	..
Lilac Spire.	1	1	1	1	1	1	45, 61
Miss California.	1	1	1	1	1	1	35, 35
White King.	1	1	0	1	1	1	25
White Spire.	1	1	1	1	1	1	34, 34
Tall Double Stock-flowered:							
Bright Rose.	1	1	1	1	1	1	28, 28
Bright Violet.	1	1	0	1	1	1	30
Dark Blue.	1	1	1	1	1	0	47
Lilac.	1	1	1	1	1	1	18, 27
Lilac Supreme.	2	18, 7	2	2	9, 9	1	..
Lustrous Carmine.	1	1	0	1	1	1	62
Pink.	1	14	1	1	9	1	..
Sky Blue.	2	9, 18	2	2	9, 11	2	..
White.	1	1	0	1	1	1	42
Total or average	24	..	19	24	..	19	36.4

each plant for a period varying from 1 to 14 days. Males were used rather than females to avoid egg deposition. The leafhoppers were then removed from the inoculated plants and played no further part in the experiment.

The method used to recover the virus from larkspurs after symptoms appeared was to feed lots of 20 previously noninfective males on each infected plant for a period of 3 days, then healthy sugar beets were exposed to the leafhoppers until symptoms of the disease developed.

Annual larkspurs infected with curly-top virus were stunted with bunched leaves at the apical end of the stem and on the axillary shoots

TABLE 2

LIST OF ANNUAL LARKSPURS EXPERIMENTALLY INFECTED WITH CELERY CALICO AND
WESTERN CUCUMBER MOSAIC AND RECOVERY OF VIRUSES

Type and variety of annual larkspur	Celery calico				Western cucumber mosaic			
	Lark- spurs inocu- lated	Lark- spurs infected	Recovery of virus from infected larkspurs		Lark- spurs inocu- lated	Lark- spurs infected	Recovery of virus from infected larkspurs	
			Cucum- bers in- oculated	Cucum- bers infected			Cucum- bers in- oculated	Cucum- bers infected
	number	number	number	number	number	number	number	number
Giant Imperial								
Double:								
Blue Bell.....	3	2	10	2	5	3	25	12
Blue Spire.....	8	8	40	40	8	6	40	26
Carmine King....	13	13	65	65	5	5	25	25
Coral King.....	3	3	15	3	3	3	15	15
Daintiness.....	6	6	30	30	5	5	25	25
Mixed.....	3	1	5	1	3	3	15	12
Exquisite Pink								
Improved.....	1	1	5	5	4	4	20	20
Exquisite Rose	7	6	30	30	5	5	25	25
Gloria.....	4	4	20	17	6	6	30	30
Hyacinth.....	5	5	25	25	5	5	25	25
La France.....	3	3	15	15	3	3	15	15
Lilac Spire.....	3	3	15	12	6	6	30	18
Los Angeles								
Improved.....	3	3	15	15	3	2	15	2
Miss California..	3	3	15	15	3	3	15	3
White King.....	3	3	15	12	3	3	15	15
White Spire.....	3	3	15	15	3	3	15	3
Tall Double Stock-								
flowered:								
Bright Rose.....	3	3	15	15	3	3	15	3
Bright Violet....	3	2	10	4	3	3	15	15
Dark Blue.....	3	1	5	1	3	3	15	15
Mixed.....	6	6	30	30	5	5	25	25
Lilac.....	5	5	25	25	5	5	25	25
Lilac Supreme....	1	1	5	5	5	5	25	25
Lustrous Car-								
mine.....	3	3	15	15	3	3	15	15
Pink.....	1	1	5	5	3	3	15	15
Rosamond.....	5	5	25	25	5	5	25	25
Roev Scarlet.....	3	3	15	9	3	3	15	15
Sky Blue.....	1	1	5	5	5	2	25	2
White.....	3	3	15	15	3	3	15	9
Total.....	108	101	505	456	116	108	550	460
Percentage....	..	93.5	..	90.3	..	93.1	..	83.6

arising from the nodes and with the lower and intermediate leaves downwardly curled (plate 2, *C*).

The incubation period of the disease varied from 22 to 33 days.

TOMATO SPOTTED WILT

Annual larkspurs frequently have been observed with black leaves under natural conditions indicating an infection of tomato spotted wilt. No attempt has been made to recover the virus from such plants nor to infect healthy plants experimentally.

WESTERN CUCUMBER MOSAIC

Annual larkspurs have not been found to be infected with western cucumber mosaic in the central-coastal regions of California, but no plants have been tested from the Sacramento and San Joaquin valleys, where the virus is known to occur.

A list of varieties of larkspurs experimentally infected by mechanical inoculation (1) is shown in table 2. A total of 116 annual larkspurs were inoculated, and 108, or 93.1 per cent, became infected, as shown in table 2. The virus was recovered from infected plants and transferred to White Spine cucumbers (table 2).

It is often difficult to detect visible symptoms of the disease on the linear segments of the leaves, but under the binocular microscope a mottling appears, consisting of elliptical, circular, or irregular chlorotic areas which coalesce later and form elongated streaks. The multifid segments of the leaves are sometimes malformed (plate 2, *B*). When larkspurs are severely affected by the disease, the plants are stunted and the leaves are bunched around the stem (plate 2, *A*). A cluster of abnormal, dwarfed flowers develops on the apical end of the stem of stunted plants but no breaking in color occurs.

SUMMARY

Annual larkspurs have been demonstrated to be naturally infected with California aster yellows, celery calico, and curly top. They have been experimentally infected with western cucumber mosaic.

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PLATES

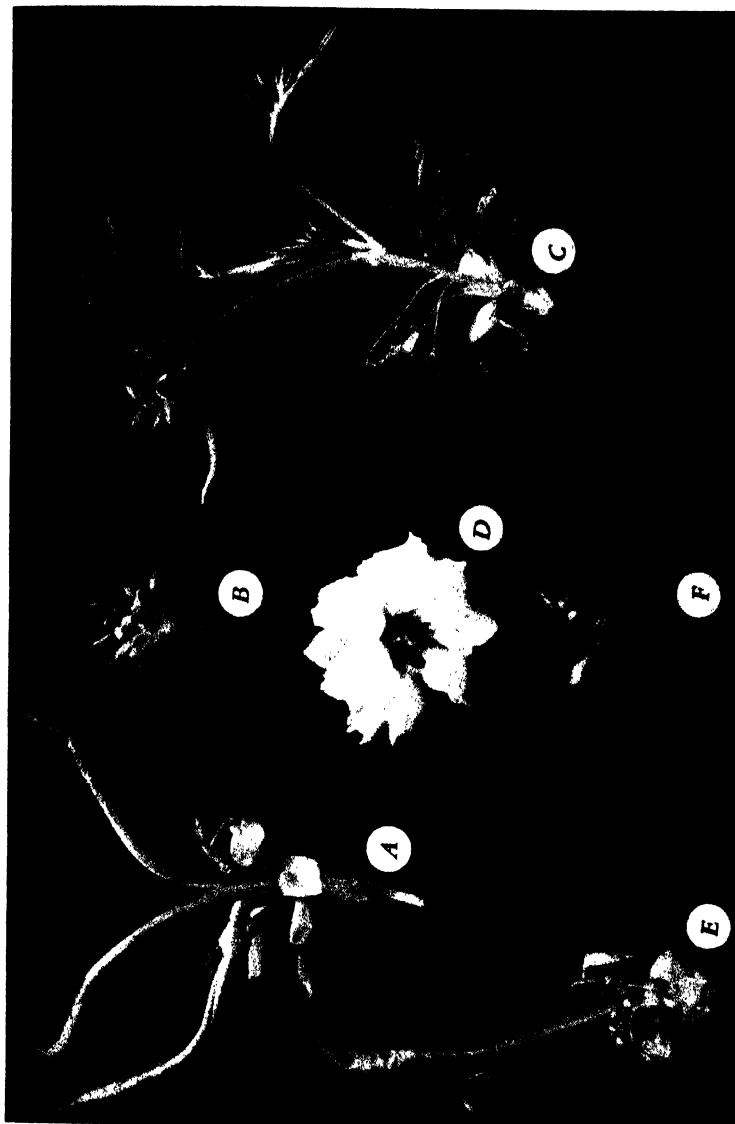


Plate 1.—Center, *D*, flower from healthy annual larkspur, others from plants infected with California aster yellows, showing phyllody and virescence; *A*, *E*, carpels leadlike, stamens apparently normal; *B*, *F*, sepals, petals, carpels, and stamens replaced by green leafy structures; *C*, carpels replaced by stems bearing variously modified appendages resembling leaves.



Plate 2.—A, B, Annual larkspur experimentally infected with western cucumber mosaic; A, entire plant stunted, with leaves bunched around the stem; B, malformed leaves. C, Annual larkspur experimentally infected with curly top showing dwarfing of entire plant with bunched leaves at the apical end of the stem and on the axillary shoots arising from the nodes, and with lower and intermediate leaves downwardly curled. D, Leaves from annual larkspur experimentally infected with celery calico showing green areas embedded in the yellow portions of the blades.

H I L G A R D I A

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ONION DOWNY MILDEW¹

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INTRODUCTION

DOWNY MILDEW of onion, caused by *Peronospora destructor* Berk., is the most important disease of the onion seed crop in California. It is serious on onions grown for bulbs and greens not only here but also in other onion-growing regions throughout the world. Though the disease probably occurs in most regions every year, severe losses are rather sporadic, as is the case with many diseases caused by downy mildews. Most previous attempts to devise control methods for the disease have been unsuccessful. The present study was started in 1935 and is devoted to various biological aspects of the disease and to its control. The work was done in the greenhouse in Berkeley unless otherwise mentioned. The principal literature concerning onion mildew is briefly reviewed, more attention being given to the controversial aspects. Most field observations were made on onions grown for seed, and generalizations in this paper refer to and are based on the California seed crop.

California grows from about 1,000 to 7,000 acres of onions for seed annually (72)³ with a production of perhaps 300,000 to 1,500,000 pounds and a value of perhaps \$300,000 to \$1,000,000 (no official estimates available). From 1918 to 1929 (72) California produced about 95 per cent of the total onion seed for the United States. Since then, partly because of destructive onion-mildew epidemics in California, some of the seed industry has been moved to Oregon and Idaho. The California bulb crop, varying from about 5,000 to 10,000 acres, produces about 1,000,000 to 1,500,000 sacks at a value of about \$1,000,000 to \$1,800,000 (?). California produced about 9 per cent of the total United States crop of onion bulbs during 1935 to 1940. By counties, in approximate order of impor-

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³ Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

tance, California onion seed is produced principally in Sacramento, Santa Clara, San Joaquin, and Sonoma counties, whereas bulbs are grown in quantity in San Joaquin, Kern, Los Angeles, Riverside, Yolo, Stanislaus, Solano, and Monterey counties (8). In Kern, Los Angeles, and Riverside counties, onion mildew has been observed in destructive amounts but has attracted less attention than in the other districts mentioned.

In California, onion seed is harvested in July and August on plants grown from mature dormant bulbs which were set in the ground the previous fall and winter. The seed-producing plants make most of their vegetative growth in the spring months, which are during the rainy season, and produce their flowers and mature their seed in the semiarid summer weather that follows. This coincidence of the vegetative-growth period with the cool, rainy season, while apparently favorable for onion growth and for high yields (28) in seasons of relative freedom from mildew, may be associated with the destructive onion-mildew epidemics that occasionally occur.

NAME, HISTORY, AND RANGE OF THE DISEASE

Onion downy mildew has also been called mildew, mold, blight, white blast, and rust, but the name downy mildew is preferred for mycological and symptomatological reasons.

Onion downy mildew was first reported in England in 1841 by Berkeley (1), but no information concerning its importance was presented at that time. Since then it has been studied intensively in the Bermuda Islands by Shipley (60); in New York by Whetzel (76), Cook (12), and Newhall (50); in Ireland by Murphy and McKay (44), and McKay (36); in Russia by Katterfeld (31); and in California by Jones, Porter, and Leach (29). In addition to the regions already mentioned, the disease is present in Asia (10), Africa (73), Australia (51), New Zealand (32), and Argentina in South America (34). With the possible exception of limited localities of unfavorable environment for the disease such as Texas (65), onion downy mildew is now considered general in its distribution.

ECONOMIC IMPORTANCE

Nature of Losses.—Onion downy mildew is important because of the large reductions in yield caused by the disease in epidemic seasons. With onions for greens, the yield reduction is direct—the injury to and killing of the leaves caused by mildew infection reduces the yield and salability of the product. Occasionally plants are killed but this is apparently rare. With onions for bulbs, the loss is indirect—mildew injury to the leaves reduces the yield and quality of bulbs. According to Murphy and

McKay (44), bulbs from an infected crop are more spongy in character and of poorer keeping quality, and systemically infected bulbs sprout prematurely in storage.

Downy-mildew infection on the onion crop for seed is the most serious aspect of the disease in California. Thaxter (66) reported that in Connecticut only seed onions were injured and that bulb onions beside infected seed onions were not infected in a single instance. Trelease (69), on the other hand, indicated that in Wisconsin the disease was more serious on young plants.

The reason onion mildew is more serious on the seed crop than on the bulb crop presumably is that the seed plants are exposed to infection for a longer period, and also that the seedstalks represent the last main growth product of the plant. If the seedstalks are injured after the leaves have already been injured or destroyed no seedstalks, or very few more, are formed by the plant in an apparent effort at recovery, whereas if the leaves of plants for bulbs are destroyed new leaves may continue to be formed by the uninjured growing point.

The leaves of well-established plants started from bulbs and grown for seed are apparently of little importance in determining the seed-yielding capacity of those plants. Jones, Porter and Leach (29) report the use of leaf pruning as a method of reducing the spread of mildew. While they give no evidence that the leaf pruning did actually reduce the incidence of mildew, they report that a good crop of seed was produced by the treated plants. To secure further information on the effect of leaf pruning, a plot of Italian Red onions growing in Berkeley was subjected to various amounts of leaf pruning. The treatments and results are given in table 1. On September 22, 1937, 10 bulbs were planted with their tops at about the soil level in each of 27 plots. Five plots were left untreated as controls, and on the others the leaves were removed at stated periods. Before seedstalks were formed, leaf pruning was performed by cutting off the leaves about 2 inches above the soil line; after seedstalks were formed, leaves were removed by cutting them off where they clasped the seedstalk or the neck below the seedstalk. Records kept of the number of plants, number of leaves, and length of leaves for some of the plots indicate that onion plants possess a remarkable power to recover after severe leaf pruning. With the exception of the plots which were defoliated four times or more, no marked stunting of the plants was apparent as a result of these treatments. No downy mildew was found in the plots, but during the summer of 1938 many of the plants became infected with *Botrytis allii* M. T. Munn, and some of the seedstalks had been destroyed by *Botrytis* before the August 5 readings were taken. Because of *Botrytis* infection it was not considered worth while

TABLE 1
EFFECT OF LEAF PRUNING ON GROWTH AND PRODUCTIVITY OF ITALIAN RED ONIONS
PLANTED SEPTEMBER 22, 1937, BERKELEY

Dates of leaf pruning	Plots	Final plants per plot on Aug. 5*	Leaves per plant							Length of leaves					Seed-stalks per plot on Aug. 5
			On Nov. 19†	On Dec. 8	On Jan. 21	On Mar. 4	On Apr. 15	On May 9	On May 24	On Nov. 19†	On Dec. 8	On Jan. 21	On Mar. 4	On Apr. 15	
None, control	number 5	number 8	number 21	number 24	number 27	number 30	number 24	number ..	number ..	inch 13	inch 18	inch 17	inch 18	inch 15	number 15
Nov. 19	1	9	..	..	..	..	..	..	..	..	..	..	..	..	number 20
Mar. 4	1	8	..	..	..	..	..	..	..	..	..	..	..	..	number 18
April 15	4	8	..	..	..	..	..	..	..	..	..	..	..	..	number 17
May 9	1	10	..	..	..	..	..	19	..	..	..	..	..	..	number 23
May 24	1	8	..	..	..	..	..	..	22	..	..	..	..	..	number 22
Nov. 19, Dec. 8	1	10	..	..	..	..	..	..	..	..	..	..	..	..	number 21
Jan. 21, May 4	1	7	..	..	..	15	13	..	..	..	..	..	12	12	number 18
Jan. 21, April 15	1	6	..	..	..	..	15	..	..	..	..	..	..	12	number 7
April 15, May 9	1	6	..	..	..	..	..	8	..	..	..	..	..	..	number 11
Jan. 21, May 24	2	10	..	..	..	..	..	..	15	..	..	..	..	..	number 25
Nov. 19, Dec. 8, Jan. 21	1	6	..	..	..	1	..	..	..	..	..	..	..	..	number 21
Jan. 21, Mar. 4, May 9	1	5	..	..	..	..	..	6	..	..	..	..	..	..	number 9
Jan. 21, April 15, May 24	1	8	..	..	..	..	..	..	9	..	..	..	..	..	number 17
Nov. 19, Dec. 8, Jan. 21, Mar. 4	3	6	..	..	..	..	..	..	..	..	..	..	..	..	number 10
Jan. 21, Mar. 4, April 15, May 9	1	8	..	..	..	..	..	6	..	..	..	..	..	..	number 9
Nov. 19, Dec. 8, Jan. 21, Mar. 4, April 15, May 9	1	5	..	10	13	14	12	7	..	..	11	12	11	11	number 10

* 10 bulbs were planted to each plot.
† 1 control plot only.

to record the seed yield of these plots. In my opinion, however, the results from this experiment corroborate the opinion of Jones, Porter, and Leach (29) that leaf pruning does not seriously interfere with seed production. As to whether such treatments will reduce the severity of downy mildew, apparently no information is available, but in cases of severe leaf infection the removal of the leaves would certainly reduce the amount of inoculum.

It is believed that onion mildew may reduce the quality as well as the yield of seed. The large numbers of shriveled seeds in heads on heavily mildewed seedstalks is direct evidence of this. In one of the procedures of cleaning onion seed, the seed is immersed in water, and the light shriveled seeds are floated off and discarded, while the heavier seed that settles to the bottom is saved. To determine if seed from heavily mildewed plants is different in its germination capacity from that of less severely infected plants, seed from the 1937 Milpitas spray plot (table 27) was subjected to a germination test. Before the seed was cleaned by immersion in water, the average percentage germination of seed from 4 control plots and from 4 plots sprayed weekly was 93 and 96 per cent, respectively; after the seed was cleaned it was 83 and 85 per cent, respectively.⁴ On the basis of this test there was little difference in the germination capacity of seed from heavily mildewed and from less severely mildewed plants, but these results may be atypical.

Another matter of possible importance in considering the nature of injury from onion mildew is sporulation injury. In tests reported in more detail elsewhere (85), the green weight of infected onion leaf tissues on which sporulation occurred averaged only 48 per cent of that of infected tissues on which sporulation was prevented. This sporulation injury was considered in part due to the transfer of food materials from host to fungus, and could not be ascribed to respiration or transpiration. The amount of carbon dioxide produced per gram dry weight of leaf tissues per hour averaged 1.29 mg for healthy leaves, 2.01 mg for mildewed nonsporulating leaves, and 1.80 mg for mildewed sporulating leaves. The respiration of sporulating mildewed tissues was thus 10 per cent less than that of nonsporulating mildewed tissues, and 40 per cent greater than that of healthy tissues; that of nonsporulating mildewed tissues was 56 per cent greater than that of healthy tissues.

Amount of Losses.—Losses from onion mildew in individual field plantings vary from none to total failure. According to Jones, Porter, and Leach (29), the loss due to mildew infection in the California seed crop from 1920 to 1938 has varied from 0 to 70 per cent in different years. I have seen individual fields of onions for greens, bulbs, and seed

⁴ Data supplied by G. W. Scott of the Associated Seed Growers, Inc.

so severely injured that the crop was not harvested. No satisfactory data from which onion-mildew severity and onion yield might be correlated over a period of years are available, but it is interesting that in 1939, when onion mildew was of little importance in California (where most of the United States onion seed is produced), the United States yield per acre of onion seed was 297 pounds, while in 1940 when mildew was severe in California the yield of onion seed for the United States was only 173 pounds per acre (71). Further data on the effect of downy mildew on yields of onion seed are given in the report of field trials of fungicides (tables 25 to 32).

In greenhouse tests, downy-mildew infection slowly kills individual leaves, stunts the plants, and occasionally kills them. To determine the amount of injury from onion mildew under greenhouse conditions, pots of seedlings varying in different tests from 15 to 35 days in age and with 10 to 50 seedlings per pot were inoculated, appropriate controls were maintained, and the green weight of the tops of inoculated and control plants were compared after incubation periods of 21 to 50 days. Only tests were used in which a high percentage of infection occurred in the inoculated plants, and several tests during the heat of the summer were discarded because of low infection. In cases where high infection occurred, there seemed to be little difference in the amount of injury from infection between trials at different seasons or between trials with incubation periods varying from 21 to 50 days from inoculation to harvest. In 16 tests in all seasons from February, 1936, to March, 1938, with an average of 5 inoculated and 5 control pots of plants in each test and with the green weight of the controls varying from 1.6 to 11.0 grams per pot and from 0.21 to 0.48 gram per plant, the green weight of the inoculated plants varied from 29 to 85 per cent and averaged 50 per cent of the controls. In these tests not all of the inoculated plants were infected, so the weight of plants actually infected would be somewhat less and the reduction in green weight due to infection would be somewhat more. Further details on the effect of mildew infection on the yield of greenhouse onions are given in table 24.

The many systemically infected plants in these tests were more severely stunted than the plants only infected locally. When weighed 40 days after inoculation, the systemically infected plants in 2 tests of 10 pots each averaged 0.25 gram per plant and the locally infected plants in the same pots 0.64 gram. Systemic infection also greatly reduces the yield and usually finally kills plants grown from bulbs (see figs. 1 and 2). In one greenhouse test, the tops of 12 systemically infected plants averaged 8.2 grams per plant 36 days after inoculation, whereas tops of 15 comparable healthy plants averaged 12.8 grams.

HOST RANGE

Peronospora destructor has been reported on the following hosts with the following records of its occurrence:

Host	Authority
<i>Allium</i> , species not recorded, but presumably <i>A. Cepa</i>	Berkeley, 1841 (1)
Welsh onion, <i>A. fistulosum</i>	Schleiden, 1846 (58)
Shallot, <i>A. ascalonicum</i>	Rhitzema Bos, 1898 (55)
<i>A. nigrum</i>	Scalia, 1900 (57)
Leek, <i>A. Porrum</i>	Schoyen, 1901 (59)
<i>A. pistulosum</i> [<i>A. fistulosum</i> ?].....	Yoshino, 1905 (86)
<i>A. ursinum</i>	Massee and Crossland, 1905 (40)
<i>A. oleraceum</i>	Treboux, 1913 (68)
Garlic, <i>A. sativum</i>	Zimmerman, 1914 (87)
Multiplier onion, <i>A. Cepa</i> var. <i>multiplicans</i>	Murphy and McKay, 1926 (44)
Egyptian onion, <i>A. Cepa</i> var. <i>bulbifera</i>	Murphy and McKay, 1926 (44)
Chive, <i>A. Schoenoprasum</i>	Cook, 1932 (12)

In a field plot at Berkeley in 1936, downy mildew was severe on several varieties of common onion and on one variety of Welsh onion, but no mildew was found on *Allium angulosum*, *A. cilicium*, *A. decipiens*, *A. flookei*, *A. giganteum*, *A. hirtifolium*, *A. montanum*, *A. moschatum*, *A. odorum*, *A. ophicorda*, *A. pallens* (so listed on tag, perhaps *A. paniculatum*), *A. paradoscum*, *A. pyrenaicum*, *A. sativum*, and *A. suaveolens*.

Varietal Susceptibility.—All commercial varieties of the common onion, *Allium Cepa*, are believed to be susceptible to downy mildew, though some varieties are more severely injured than others, and the development by hybridization of varieties with a high degree of resistance is under way (29). The mildew susceptibility of several commercial onion varieties grown for seed and for bulbs was studied in field plantings at Davis, Berkeley, and Milpitas, and in greenhouse plantings at Berkeley. As there are several methods by which mildew incidence can be determined and varietal susceptibility rated, this matter merits some discussion here.

Three methods of determining mildew incidence are: (1) microscopic observation of tissues for characteristic mycelium, haustoria, and oöspores, (2) determination by the characteristic symptoms, and (3) determination by presence of sporangiophores and sporangia. Microscopic observation of tissues is useful and essential in doubtful cases, and has been extensively used by Murphy and McKay (44), but it is too laborious for most studies. The detection of the disease by symptoms is perhaps the most useful method of diagnosis but is subject to error unless one is well acquainted with the disease. One of the most common injury symptoms on onions is the dying of leaf tips. Although this injury may be

TABLE 2
SUSCEPTIBILITY TO ONION DOWNY MILDEW OF ONION VARIETIES GROWN FOR SEED

Variety	1936 Berkeley plot, seedstalks infected, June 13		1937 Milpitas plot		1938 Milpitas plot				1939 plots			Severity on leaves,* Davis plot, April 10
	per cent	Leaves infected, March 23	Severity on seedstalks,* June 15	Leaf tissue injured		Sporulation,* April 6	Severity on seedstalks*		Severity,* Milpitas plot			
				per cent	May 27		May 27	July 5	On leaves, May 5	On seedstalks, May 26		
											rating	
Alisa Craig	14	—	—	26	63	7.1	1.2	6.1	—	—	—	1
Australian Brown	—	—	—	—	—	—	—	—	—	—	—	—
California Early Red	30	84	6.2	39	100	8.6	9.8	10.0	—	—	—	—
Crystal White Wax	—	—	—	—	—	—	—	—	—	—	—	—
Danvers Flat	10	—	—	22	83	4.5	3.7	7.4	8.0	8.0	8.0	6
Early Grano	14	—	—	29	83	6.6	3.9	9.0	8.7	6.0	6.0	8
Early Yellow Globe	—	—	—	—	—	—	—	—	—	—	—	—
Early Snow	37	—	—	—	—	—	—	—	—	—	—	—
Early Express	42	—	—	—	—	—	—	—	—	—	—	—
Ebeneser	28	—	—	23	80	5.6	3.6	4.5	5.0	1.3	1.3	1
Giant White Italian Tripoli	42	—	—	—	—	—	—	—	—	—	—	—
Italian Red (inbred)	29	54	1.4	—	—	—	—	—	—	—	—	0
Italian Red 13-33	—	2	0	—	—	—	—	—	—	—	—	—
Ivissa (F.P.I. 64449)	67	—	—	—	—	—	—	—	—	—	—	—
Lord Howe Island	42	75	6.9	25	97	7.8	4.3	8.9	—	—	—	8
Ohio Yellow Globe	12	—	—	—	—	—	—	—	—	—	—	—
Nebuka	100	—	—	—	—	—	—	—	—	—	—	—
Prizetaker	23	—	—	—	—	—	—	—	—	—	—	—
Red Croole	81	—	—	—	—	—	—	—	—	—	—	—
Red Rocco	—	74	9.5	21	49	7.9	5.8	8.0	—	—	—	—
Red Wethersfield	—	38	—	84	84	7.2	10.0	10.0	—	—	—	—
Southport White Globe	53	—	—	27	83	6.7	6.2	8.6	3.8	1.6	1.6	—
Southport Yellow Globe	—	—	—	28	95	6.2	5.7	8.3	—	—	—	—
Stockton Yellow Globe	30	58	5.8	—	—	—	—	—	—	—	—	—
Utah Sweet Spanish	33	83	—	16	89	4.4	1.8	5.2	—	—	—	0
White Persian	75	—	—	—	—	—	—	—	—	—	—	10
White Portugal	20	—	—	27	77	7.8	4.6	8.1	6.6	3.0	3.0	—
Yellow Bermuda	90	—	—	34	100	7.6	9.9	10.0	8.7	7.2	7.2	—
Yellow Globe Danvers	—	—	—	29	91	5.0	7.2	9.2	5.3	1.3	1.3	1
Yellow Strasburg	43	—	—	—	—	—	—	—	—	—	—	—

* In rating relative injury an arbitrary scale of 0 to 10 was used in which 0 indicated no injury and 10 indicated killing of leaf. Intensity of sporulation was also rated on an arbitrary scale of 0 to 10.

† Dashes indicate data not available.

caused by downy mildew, it is also caused by *Botrytis cinerea* Auct. and other, unknown causes, presumably unfavorable soil or weather conditions associated with or in the absence of downy mildew. The occurrence of downy-mildew sporophores on the surface of living onion leaves is the most reliable index of downy-mildew infection, but unfortunately sporulation does not occur with regularity under field conditions.

There are several methods by which varietal susceptibility can be rated. The determination of the percentage of plants infected is useful in comparing the incidence of systemic infection and in comparing the amount of local infection when the incidence of disease is low, but it is of little value in most field tests such as I have observed, where most of the plants are infected in varying degrees of severity. Murphy and McKay (44) determined the percentage of plants killed by the disease in one set of comparisons of varieties, but the killing of the plants has been too rare and too slow under the conditions of my observations to make this a useful method. The method I would consider ideal for making comparisons of the susceptibility of varieties to a disease such as downy mildew, the main economic effect of which is to reduce yield, would be to determine the comparative yield reduction due to mildew in several varieties. However, until a satisfactory way can be devised for maintaining healthy control plants under field conditions favoring mildew development, this method cannot be used.

In this study the methods considered most useful for recording varietal susceptibility in the field have been the determination of the percentage of leaves or seedstalks infected, the estimation of the percentage of the leaf tissue showing injury, and the rating of the relative amount of injury or sporulation on leaves or seedstalks. In estimating percentage of leaf tissues showing injury, an independent estimate was made for each of several plants of each variety, and these values were averaged to secure the value for the variety. In rating the relative injury an arbitrary scale of 0 to 10 was used, in which 0 indicated no injury and 10 indicated killing of the leaf; each of several plants of each variety was rated independently and averaged. The intensity of sporulation was also rated on an arbitrary scale of 0 to 10.

The relative mildew susceptibility in the field of several onion varieties as observed in Davis, Berkeley, and Milpitas by different methods of rating is summarized in table 2. The numbers of plants on which these ratings are based were small (the 1936 plot averaged 9 plants per variety and 2 as the minimum number), but I believe the values of table 2 indicate real differences between varieties, though these values are not so satisfactory as yield records would be. The varieties listed as Italian Red (inbred) and Italian Red 13-53 are selections described by Jones, Porter,

TABLE 3
SUSCEPTIBILITY OF ONION VARIETIES TO DOWNY MILDEW IN GREENHOUSE

Variety	Plants from bulbs inoculated by spraying, November, 1936			Seedling plants inoculated by spraying, April, 1937		Seedling plants inoculated by spraying, March, 1938		Dormant bulbs inoculated hypodermically, October, 1940		
	Leaves per plant	Leaves infected	Spore-lation*	Plants	Plants infected	Plants	Plants infected	Plants	Plants with systemic infection	Plants with local infection only
	number	per cent	rating	number	per cent	number	per cent	number	per cent	per cent
Brown 5.....	—†	—	—	—	—	—	—	10†	30	0
California Early Red.....	62	94	5	105	99	—	—	—	—	—
Crystal White Wax.....	—	—	—	190	94	—	—	—	—	—
Early Grano.....	—	—	—	—	—	—	—	11	82	0
Ebenezer.....	—	—	—	100	70	—	—	—	—	—
Italian Red 13-53.....	80	72	5	—	—	—	—	12	17	25
Italian Red 13-53 X Red 21.....	—	—	—	—	—	117	84	—	—	—
Italian Red 13-53 X 21-22-1.....	43	77	6	—	—	—	—	—	—	—
Italian Red 13-53 X Lord Howe Island.....	—	—	—	—	—	210	78	—	—	—
Italian Red 13-53 X Sweet Spanish.....	—	—	—	—	—	—	—	11	73	9
Italian Red 13-53 X Australian Brown.....	—	—	—	—	—	—	—	11	27	36
Lord Howe Island.....	—	—	—	69	91	135	82	—	—	—
Red 21.....	—	—	—	—	—	118	90	—	—	—
Stockton Yellow Globe.....	—	—	—	52	90	—	—	—	—	—
Sweet Spanish.....	—	—	—	137	97	—	—	—	—	—
White Persian.....	—	—	—	105	97	—	—	—	—	—
Yellow Bermuda.....	—	—	—	—	—	—	—	10	100	0

* In rating sporulation an arbitrary scale of 0-10 was used in which 0 indicated no sporulation, and 10 indicated maximum sporulation.

† Dashes indicate data not available.

‡ These bulbs grew very slowly and this may account for the low infection.

and Leach (29) and used by them in a breeding program aimed at the development of mildew-resistant onions. Among the susceptible varieties White Persian and Yellow Bermuda are outstanding, and mildew has been so severe as to make seed production of these varieties impractical at Milpitas. For this reason, Yellow Bermuda was an ideal variety for tests of fungicidal control (see tables 25, 29, and 31). Among varieties more tolerant to downy mildew are Australian Brown, Utah Sweet Spanish, and Ebenezer. The relative tolerance to mildew of Yellow Bermuda and Australian Brown may be usefully compared by considering the 1937 spray plot on Australian Brown (table 28) with the 1938 spray plot on Yellow Bermuda (table 29). While those were seasons of approximately equal mildew severity at Milpitas, the yield of untreated Australian Brown in 1937 was greater than the yield of twelve-times sprayed Yellow Bermuda in 1938, even though the disease control from spraying was marked in both years.

Greenhouse tests to determine the relative susceptibility of onion varieties were not extensive and were not highly successful, but 4 tests are reported in table 3. In the test of November, 1936, several bulb plants of each of 3 varieties were inoculated, and the number of leaves infected and the relative intensity of sporulation were compared. No marked differences in these varieties were apparent from this test, though field tests show that Italian Red 13-53 is more resistant than the other strains. In the test of April, 1937, differences between greenhouse seedlings were not marked, though Ebenezer, showing least infection in this test is also somewhat resistant under field conditions. In the test of March, 1938, also, the differences between varieties were small and probably not significant. In the test of October, 1940, bulbs of 6 varieties were inoculated hypodermically with a spore suspension. In this test Early Grano and Yellow Bermuda, known to be highly susceptible under field conditions, showed the highest amount of systemic infection. Italian Red 13-53, known to be highly resistant in the field, showed the lowest amount of systemic infection. The results with Italian Red 13-53 $\times$ Sweet Spanish and Italian Red 13-53 $\times$ Australian Brown show these to be intermediate in susceptibility, as might be expected from field tests. The results with Australian Brown are probably unreliable because of delayed growth.

RESISTANT VARIETIES

What is perhaps the only effort to develop onions resistant to downy mildew has been reported by Jones, Porter, and Leach (29). Jones and his associates isolated 3 strains of onions resistant to downy mildew and have used these in an extensive breeding program aimed at the development of mildew-resistant strains of commercial onions. The results at

present appear promising, and some of these parent strains and hybrids of them have remained resistant to onion mildew and produced high yields under epidemic conditions for the disease at Milpitas, while plantings of several commercial varieties were almost destroyed by mildew (table 2). The ultimate and permanent success of such a program would make unnecessary any other control practices for this disease. In such a program, however, there is always the danger that strains of the organism capable of causing injury to the new varieties will appear.

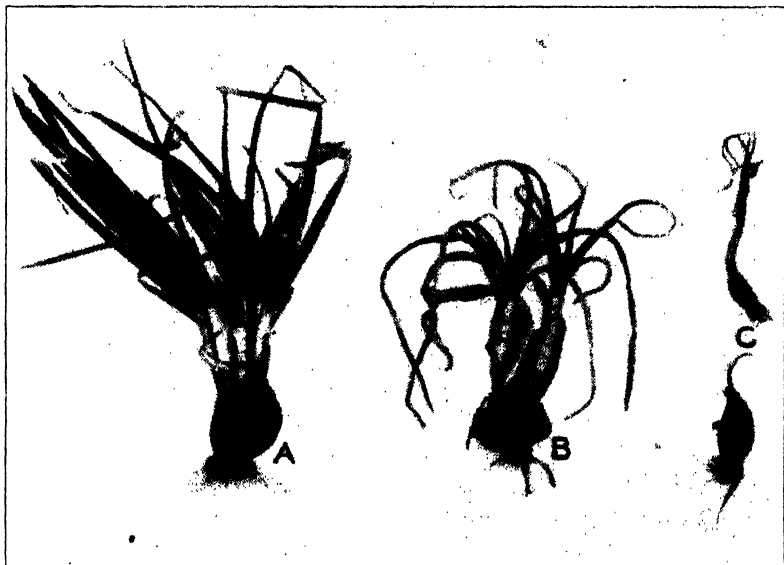


Fig. 1.—Effect of systemic infection with onion downy mildew on plants of Stockton Yellow Globe onions grown for seed at Milpitas. Photographed February 21, 1939. *A*, Typical plant, showing no systemic infection with downy mildew but showing a characteristic killing of the leaf tips, the cause of which was not determined for this material, and some local white infection spots caused by *Botrytis cinerea*; *B*, systemic infection on a plant that was healthy on November 7, 1938; *C*, plants which showed systemic infection on November 7, 1938.

No extensive studies of the nature of resistance in the onion strains developed by Jones, Porter, and Leach (29) have been made. In greenhouse cultures, sprayed water adhered less readily to the leaves of mildew-resistant Italian Red 13-53 plants and to leaves of intermediate susceptibility from white bulbs of an unknown variety than to leaves of the highly susceptible Yellow Bermuda. In the field at Milpitas, however, no marked difference in the retention of rain water or dew by the leaves of several strains with known differences in resistance could be observed.

SYMPTOMS

Assuming that onion downy mildew oversummers as mycelium in dormant bulbs, the first symptoms to be observed on onions grown for seed from bulbs are the pale-green, down-curved, and narrow leaves of the systemically infected plants (figs. 1, 2). On systemically infected plants growing in the greenhouse, two symptoms not previously recorded have been frequently observed. On some leaves whitish diffuse spots (fig.



Fig. 2.—Effect of systemic infection on Red Creole and Yellow Bermuda onions grown in Berkeley. Three plants at left are healthy, 3 plants at right show systemic infection. In each group of 3 plants, the 2 plants on the left are Yellow Bermuda and the single plant on the right is Red Creole. Planted August 25, 1938; photographed October 3, 1938.

3) somewhat similar to lesions caused by *Botrytis cinerea* (fig. 4) appear. These spots differ from *Botrytis* lesions, however, in not being depressed, and in being less necrotic. Whereas *Botrytis* lesions are elongated in the direction of the long axis of the leaf and about twice as long as wide, the lesions associated with systemic downy-mildew infection are not infrequently wider than they are long. That these lesions are not due to an external infection is indicated by the fact that they appeared on plants kept in a dry environment, and that adjacent nonmildewed plants showed no such symptoms. The other unreported symptom associated with systemic infections is the appearance in spots of whitish crystalline-appearing deposits on the surface of systemically infected leaves.

Primary infection, resulting from systemically infected bulbs, and giving rise to the symptoms just described, is rarely observed, whereas secondary, or external, infection, from sporangia produced by primary infections, is responsible for the well-known and frequently described

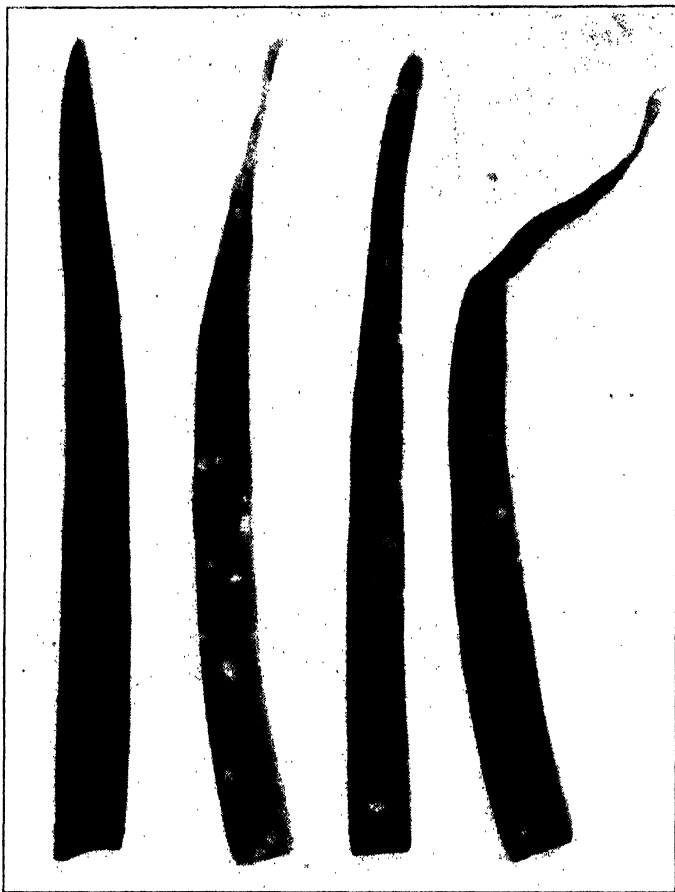


Fig. 3.—Localized spotting of onion leaves associated with systemic infection with onion downy mildew. Leaf on left is from healthy plant. Three leaves on right are from systemically infected plants grown in the greenhouse from bulbs inoculated October 26, 1940. Photographed December 2, 1940.

symptoms of onion mildew on leaves and seedstalks. Secondary symptoms consist of oval to cylindric, local lesions usually 3 to 30 cm in length (figs. 5, 6, 7, 8) which appear on leaves and seedstalks. These lesions, always elongated in the direction of the long axis of the leaf, may show no symptoms until after sporulation; they may show as uniformly pale

areas; or they may show as concentric ovals or arcs of slightly chlorotic tissue alternating with tissues of a slightly different shade of green. These large, smooth-margined, oval lesions caused by onion mildew are in marked contrast to the symptoms of many other downy mildews such as

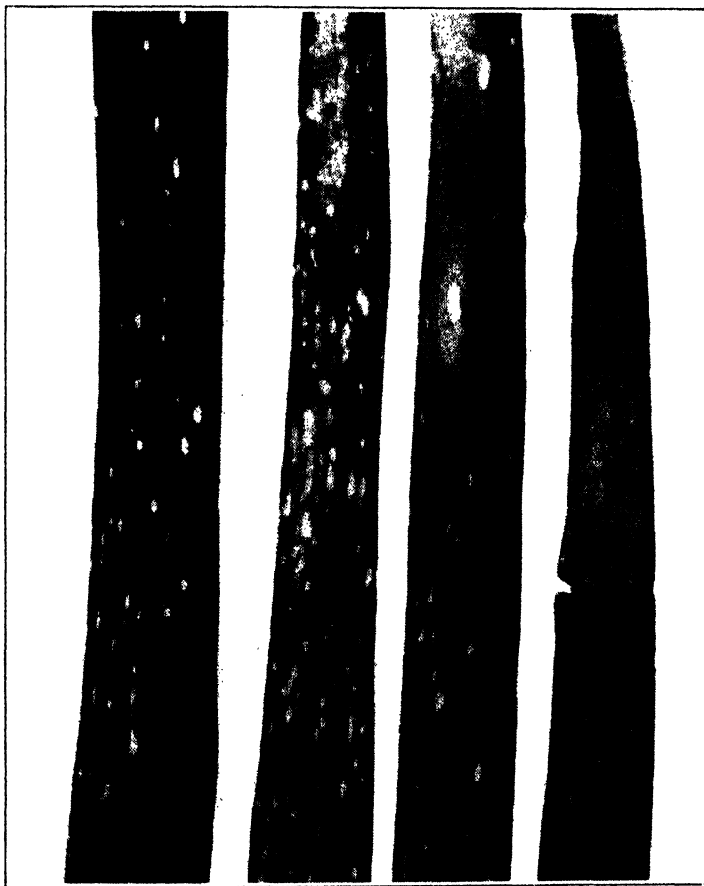


Fig. 4.—White spotting of onion leaves, caused by *Botrytis cinerea*, from plants grown at San Pablo. Leaves from left to right show progressively increasing injury from infection. Photographed February 9, 1940.

those of hop, cucumber, lettuce, and grape, where the lesions on the leaves are usually small, angular, and bounded by the veins. This difference between onion mildew and the other mildews mentioned is believed to be due to the difference in morphology between onion leaves and the leaves of the other hosts mentioned. In onion, the vascular bundles of the leaves and seedstalks are not mechanical or only slightly so (see fig. 11) and

offer little obstruction to the lateral growth of the fungus. The lesions are elongate in the direction of the long axis of the leaf presumably because most of the host cells, other than the palisade parenchyma, are elongated in the same direction.

Infected onion leaf tissue may die without the occurrence of sporulation, but the latter hastens death of infected tissue. The centers of the lesions usually become necrotic first; infection with a secondary in-

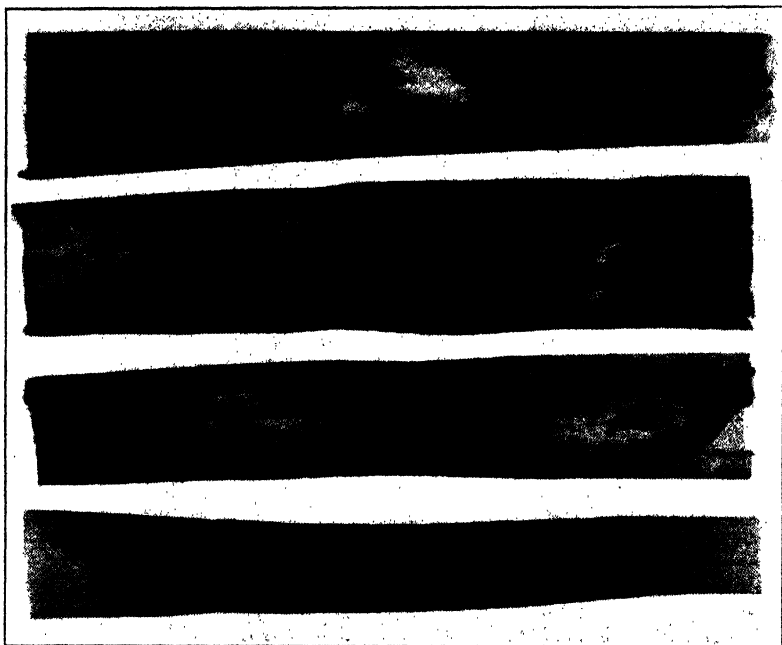


Fig. 5.—*Macrosporium* infection on onion seedstalks previously infected with onion downy mildew; specimens from Cotati. The zonate character is the same basic pattern as shown earlier (see fig. 8) by downy-mildew infection in absence of *Macrosporium*. Photographed July 17, 1940.

vader, *Macrosporium*, usually apparently precedes death of the tissues from mildew infection and is apparently responsible for the rapid killing of tissues already weakened by mildew infection. Early-occurring mildew lesions on leaves or seedstalks generally girdle the organ, and all tissues beyond the lesion may die. In cases of heavy infection, the older outer leaves are progressively killed back to the leaf sheath (fig. 9), while even in the later severe stages of the disease the younger leaves may show only killing of the leaf tips with the base of those central leaves apparently healthy. This type of symptom is a consequence of the manner of growth of the onion. The outer leaves are the older, and after

they have reached a fair length they stop growing, while leaves of intermediate age are still growing, and still younger central leaves are being formed. As the growth of onion leaves is from the base, infected tissues

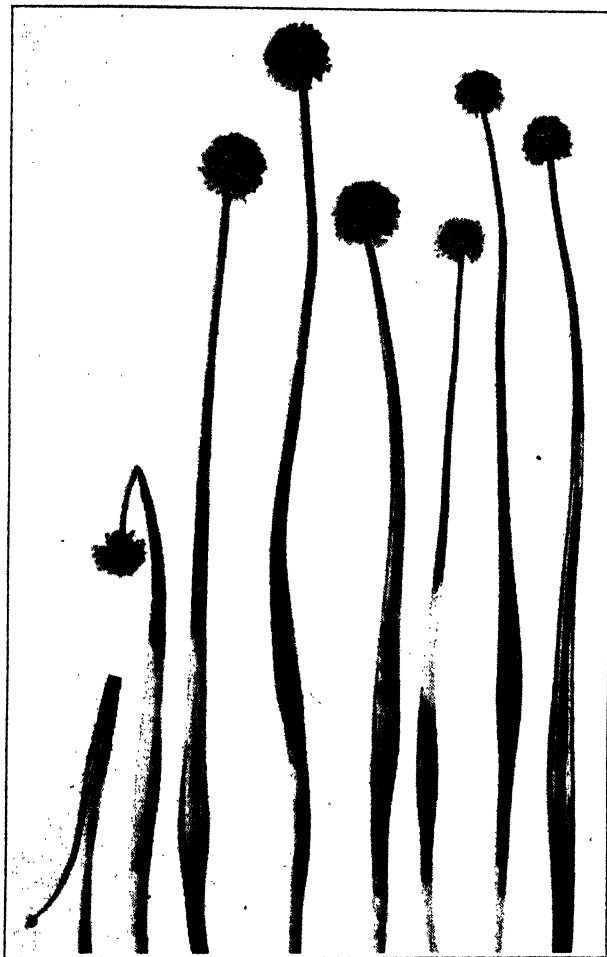


Fig. 6.—Onion-downy-mildew infection of various degrees of severity from complete killing of the seedstalks (extreme left) to healthy seedstalk (extreme right); specimens from Cotati. Photographed July 17, 1940.

on these leaves are being pushed farther away from the base of the plant, and as the infected tissues die a tip-blight condition of the leaves becomes apparent. As the mildew lesion is growing while the leaf is growing, however, the symptoms expressed by the plant may be considered as a balance between several forces, the most important of which are the upward



Fig. 7.—Bending and twisting of onion seedstalks caused by onion-downy-mildew infection; specimens from Cotati. Infection on one side of a seedstalk apparently may cause the cells on that side to cease elongating, and thus the stem bends toward the side with the mildew lesion. Later the lesion usually girdles the seedstalk. Photographed June 3, 1941.

growth of the leaves, the downward growth of the mildew fungus, and the number of new secondary infections.

In the field the downward growth of the mycelium and the number of secondary infections are frequently sufficient to kill all the leaves, first the outer leaves and then the inner. Presumably, as the outer leaves are

killed the rate of growth of the inner leaves is decreased because of decreased food supply, and they are thus more subject to complete invasion though perhaps no more susceptible.



Fig. 8.—Onion leaves with chlorotic areas caused by mildew infection. The leaf at the right shows the zonate character of the chlorotic lesion which is characteristic of many lesions. Photographed May 15, 1941.

In the greenhouse with a temperature at about 20° C, onion leaves of plants grown from bulbs develop rapidly. By marking the point of emergence of leaves from the sheath, onion leaves have been observed to grow as much as 1 inch in 24 hours. When such greenhouse plants are inoculated, all the exposed tissues are usually invaded by the fungus which moves down from the point of inoculation. Outer, nongrowing leaves and the tips of leaves that were exposed at the time of inoculation may

be killed, but so rapid is the growth from below that, in the absence of further secondary infection, the amount of healthy tissue is soon greater than the amount of diseased tissue, and, as new leaves are formed



Fig. 9.—Onion-downy-mildew infection on onions grown for greens, showing the severe tip blight and killing of the lower leaves; from plants grown at Bay Farm Island. Photographed December 15, 1939.

and the older ones are killed back, the plants soon show only healthy living leaves and dead outer leaves. As older outer leaves frequently die in the absence of downy mildew or other known disease, such recovered plants present almost a normal appearance. This process of apparent complete recovery has not been observed in the field. With the exception

of differences apparently determined by rate of leaf growth and amount of secondary infection, as already described (p. 612), leaf symptoms are basically similar in field and greenhouse infections. Seedstalk infection has not been studied to any extent in the greenhouse.

Seedstalks appear somewhat more resistant to infection injury and are less likely to show sporulation than onion leaves. Systemically infected seedstalks are rare, presumably because systemically infected

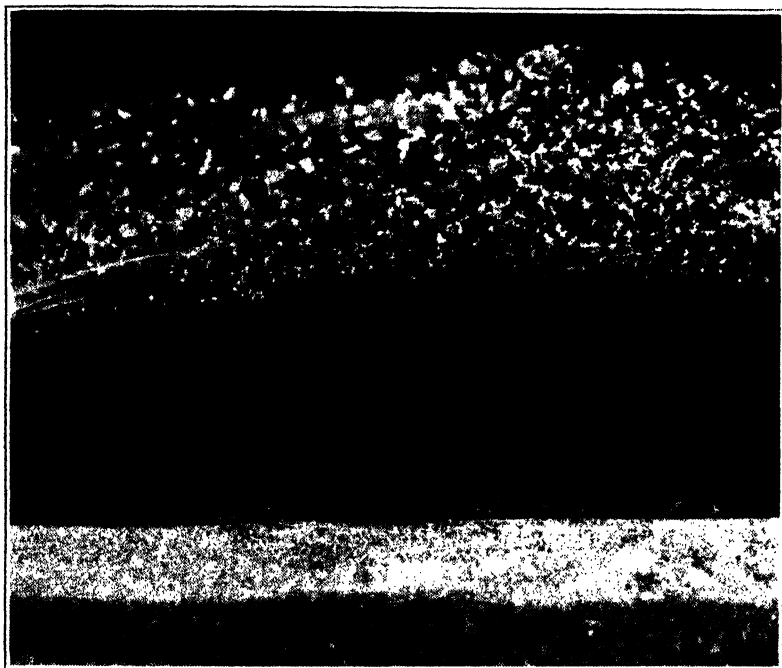


Fig. 10.—Sporulation of *Botrytis cinerea* Auct. (upper) and *Peronospora destructor* Berk. (lower) on same onion leaf ($\times 8$). The *Botrytis* infection is on the killed tip of a leaf which showed infection of onion downy mildew on the lower living portion of the leaf. The sporulation of *P. destructor* is more sparse than usually observed.

plants usually die before seedstalks are formed or the plants are too weak to form them. A common site of local seedstalk infection is a few inches below the head, and infection here and on other portions frequently cause the stalks to bend and curl into various unusual positions (fig. 7). The mildew lesion is usually centered at the inside of the bend, and the bending is apparently caused by the continued linear growth of noninfected tissues while growth is stopped or reduced in the infected tissues. Seedstalks thus affected are usually more rigid than erect, healthy seedstalks. This twisting of the seedstalks is a very striking

symptom on some varieties before there has been much killing of the tissues. Infected areas at the upper end of the seedstalk appear less likely to be invaded by *Macrosporium* than infected areas in the central or lower regions.

Sporulation results in a grayish-violet downy layer of sporangiophores and sporangia of the causative organism (*Peronospora destructor*) on the leaf surface. These sporangiophores and sporangia are the signs of onion downy mildew, and are somewhat similar to, though easily distinguished from, the conidiophores and conidia of *Botrytis cinerea* (fig. 10). Their morphology is described in the next section.

NOMENCLATURE AND DESCRIPTION OF CAUSAL ORGANISM

Peronospora destructor Berk. is a typical downy mildew of the family Peronosporaceae. This binomial with Berkeley as the sole authority has apparently not previously been used and therefore an explanation is in order. Onion downy mildew was first recorded in 1841 by Berkeley (1), who illustrated and described the imperfect stage and named it *Botrytis destructor*, though from his description it is obviously a downy mildew, as we now understand this group. In 1846, Schleiden (58, p. 38) illustrated an organism on *Allium fistulosum* and referred to it as *B. (parasitica ?)*, though his illustration is obviously also that of a downy mildew. In 1847, Unger (70) gave a Latin description of what appears to be the same organism under the name of *P. Schleideni* Ung. In 1860 Berkeley (2, p. 348) indicated that in view of recently acquired knowledge of the oöspores of the group *Peronospora*, the organism he originally described as *B. destructor* should be called *P. destructor* Casp. It is not clear from Berkeley's discussion whether or not he saw the oöspores of the onion-mildew organism, or why he cited Caspary as the authority for his new name. De Bary (13) in 1863 refers to the onion-downy-mildew organism as *P. Schleideniana* Unger, though Unger used the spelling *Schleideni*. Worthington Smith (62) in 1884 was perhaps the first to record with relative certainty and illustrate the oöspores of the onion-downy-mildew organism.

For the past forty years the name *Peronospora Schleideni* Ung. has been the most widely used binomial for the organism causing onion mildew. There are obvious reasons, however, why it may be considered invalid, and the nomenclature of this organism has been considered in detail by Wilson (77), Cook (12), and Wakefield and Moore (74). Wilson and Cook accept the name *P. destructor* (Berkeley) Caspary on the basis of priority, using Caspary as an authority for the genus, though with reluctance, because Berkeley had used it. Wakefield and

Moore, interpreting article 37 of the *International Rules of Botanical Nomenclature* (3) as applying to the Phycomycetes, and believing that Berkeley was not aware of the oöspores of the onion-mildew organism, feel that the name should be *P. Schleideniana* W. G. Smith. In article 37 of the *International Rules*, however, the Phycomycetes are not mentioned, and the Peronosporaceae are usually classified on the basis of their imperfect stages. I agree with Wilson and Cook that the name should be *P. destructor*, but cannot accept their reason—probably an old manuscript name (77, 12)—as adequate for including Caspary as the second authority for this name. Even if article 37 of the *International Rules* is considered applicable here, it might still be reasoned that the name should be *P. destructor* Berk. since Berkeley transferred it to the genus *Peronospora* because he believed it possessed an oöspore stage.

The synonymy of *Peronospora destructor* Berkeley is as follows:

- Botrytis destructor* (Berkeley, 1841) (1)
Botrytis (parasitica) ? (Schleiden, 1846) (58, p. 38)
Peronospora Schleideni (Unger, 1847) (70)
P. destructor Casp. (Berkeley, 1860) (2)
P. Schleideniana Unger (De Bary, 1863) (15)
P. Alliorum (Fuekel, 1870) (21)
P. Schleideniana De Bary f. *Cepae* (Thuemen, 1879) (67)
P. destructor (Berk.) Caspary (Wilson, 1914) (77)
P. Schleideniana W. G. Smith (Wakefield and Moore, 1936) (74)

From material I have collected and examined, the morphology of *Peronospora destructor* is as follows (see fig. 11):

Sporangiophores nonseptate, various shades of violet, emerging from stomata, 122 to 820 μ in length, 7 to 18 μ in diameter at swollen base, tapering to acute sterigmata at tips, two to six times monopodially branched, 3 to 63 sporangia per sporangiophore. Sporangia pyriform to fusiform, attached to sporangiophore by pointed end, 18 to 29 μ by 40 to 72 μ , thin walled, slightly papillate at proximal end, germinating by 1 to 2 germ tubes from near region of proximal end. Germ tubes penetrate host through stomata and usually form an appressorium over stomatal opening and a substomatal vesicle in substomatal cavity. Mycelium nonseptate, intercellular 4 to 13 μ in diameter. Haustoria filamentous, coiled within cells, 1.3 to 5.0 μ in diameter. Oögonia 43 to 54 μ , oöspores 40 to 44 μ .

This description differs from some previous descriptions of the onion-mildew fungus and therefore several controversial aspects of the morphology of the organism will be considered in more detail. I have seen only nonseptate sporangiophores, though septate sporangiophores are illustrated by Smith (62) and Massee (39). Throughout this paper the terms sporangiophores and sporangia will be used in place of, though synonymous with, the terms conidiophores and conidia of most previous investigators, for reasons given by Fitzpatrick (20). The greater

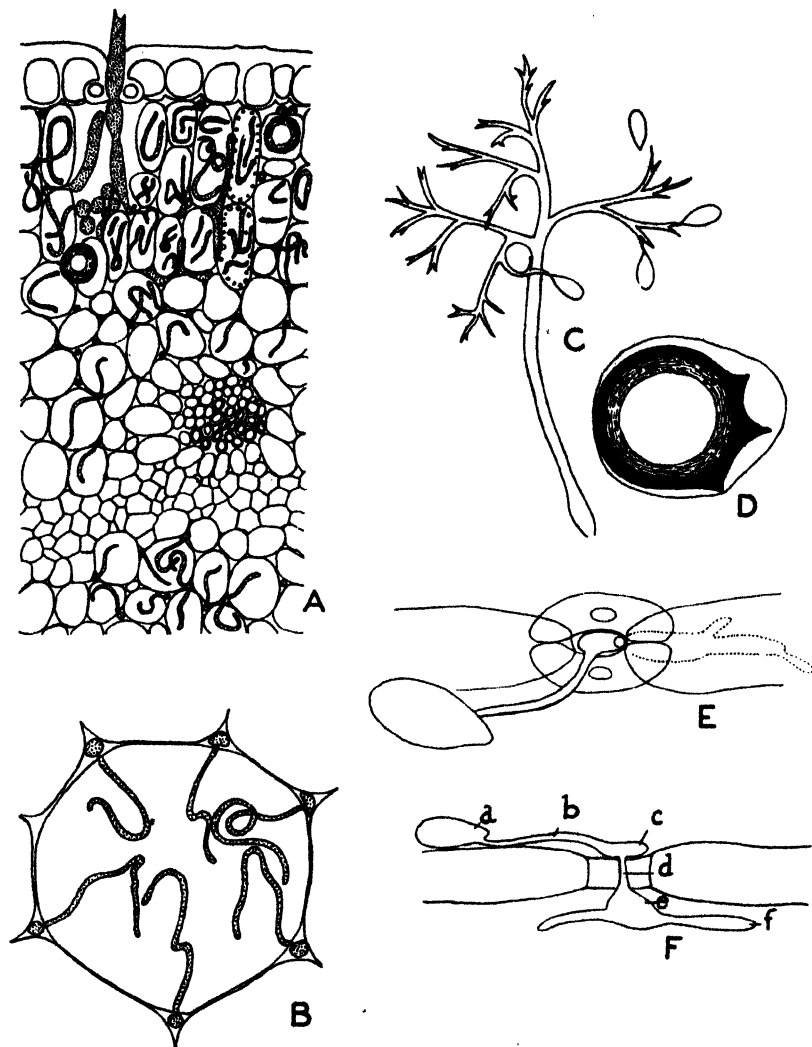


Fig. 11.—A, Cross section of onion seedstalk showing mycelium, haustoria, oöspores, and sporangiophores of *Peronospora destructor* Berk. in infected tissues ($\times 107$). B, Cross section of parenchyma cell showing intercellular mycelium and intra-cellular haustoria ($\times 255$). C, Sporangiophore and sporangia ($\times 255$). D, Approximately mature oöspores ($\times 510$). E, Stomatal penetration as observed in epidermal strip from inoculated leaf ($\times 510$). F, Diagrammatic representation of E in radial section (not observed in this manner): a, sporangium; b, germ tube; c, appressorium; d, penetration tube; e, substomatal vesicle; f, infection hypha.

variation in the length of the sporangiophores than previously reported is presumably because the limits recorded in this paper are from temperature and humidity tests, to be presented later (p. 635), and the length of the sporangiophores is greater at higher temperatures and higher relative humidities.

As I have observed them, the sporangiophores of *Peronospora destructor* are monopodially^a branched, while according to Fitzpatrick (20), Saccardo (56), and others, the genus *Peronospora* is characterized by dichotomous branching. Saccardo, describing *P. destructor* under the

TABLE 4
COMPARISON OF BRANCHING OF SPORANGIOPHORES OF *Peronospora destructor*
AS OBSERVED BY DIFFERENT WORKERS

Authority	Sporangiophores	Average of ultimate branches per sporangiophore	Percentage of ultimate branches on first branch from main axis
	number	number	per cent
Berkeley, 1841 (1).....	1	16	37
Schleiden, 1846 (58).....	1	13	23
Smith, 1884 (62).....	2	23	35
Shipley, 1887 (60).....	3	22	21
Whetzel, 1904 (76).....	2	23	35
Duggar, 1909 (17).....	1	22	27
Murphy and McKay, 1928 (44).....	1	109	32
Owens, 1928 (53).....	1	20	25
Newhall, 1939 (50).....	63	16	—*
Yarwood, Jan. 9, 1935.....	8	25	—*
Yarwood, Jan. 24, 1940.....	8	50	34

* Dashes indicate data not taken.

name *P. Schleideni*, includes the character of dichotomous branching, but the first illustration and description of the fungus by Berkeley (1) indicates definite monopodial and alternate branching of the sporangiophores. In later illustrations by Schleiden (58), Smith (62), Shipley (60), Whetzel (76), Duggar (17), Murphy and McKay (44), and Owens (53), the branching is distinctly monopodial in most cases. To secure more quantitative information on the branching character of *P. destructor*, measurements were made of material collected by myself as well as from illustrations of previous investigators, and the number of ultimate branches on the first branch from the main axis is expressed as a percentage of the total number of ultimate branches (table 4). If the branching were dichotomous it would be impossible to choose a main axis, and the number of ultimate branches on either of the primary branches should approach 50 per cent of the total. From the calculations

^a *Monopodial* means possessing a main axis and having secondary side branches; *dichotomous* means with no main axis and with branches of equal size at each division of the main or subsequent stems of the sporangiophore.

of table 4, the maximum number of ultimate branches on the first main branch was 37 per cent of the total (1), the minimum was 21 per cent (60), and the average was 30 per cent. The illustration chosen arbitrarily by myself (fig. 11) shows 40 per cent of the ultimate branches on the first main branch and is therefore slightly abnormal. If dichotomous branching is an important character of members of the genus *Peronospora*, then onion mildew should not be in this genus.

The number of ultimate branches, or sporangia, per sporangiophore, is an extremely variable character (table 4), and in my tests has varied from 3 (found in one test at 7° C) to 63, while Murphy and McKay (44) illustrate a sporangiophore with 109 ultimate branches.

The large pyriform sporangia of *Peronospora destructor* are easily distinguishable from the sporangia of most other downy mildews and of most other fungi, but the shape of the sporangia shows considerable variation. In the illustrations of Schleiden (58) and Smith (62), the sporangia are ovate to cylindrical with rounded ends. Illustrations by Dudley (16) indicate fusiform sporangia, and my cultures, in which sporangia were produced at 22° C, showed predominantly fusiform sporangia, though at lower temperatures they were predominantly pyriform. Sporangia formed in strong artificial light were sometimes constricted in the middle. Duggar (17) illustrates the sporangia attached to the sporangiophores by the large rounded end, but in my observation they are always attached at the small pointed end.

Clements and Shear (11) indicate that the sporangia of *Peronospora* are not papillate at the tips, and use this character to separate *Peronospora* from *Btëmia*. A semblance of a papilla, however, can sometimes be clearly seen at the proximate end of the sporangia of *P. destructor*. The mycelium of *P. destructor* is generally regarded as nonseptate, but McKay (36) describes and illustrates septate mycelium arising from germinating oöspores. McKay also describes chlamydosporelike bodies on special branches of the mycelium from germinating oöspores.

Oöspores do not occur with regularity in infected tissues, and the causes underlying their formation have not been determined. Some lesions may show them in abundance, whereas other similar-appearing lesions may show none. I have found them more abundant in seedstalk lesions than in leaves, but they may also occur in abundance in locally and systemically infected leaves. In seedstalks I have seen them most abundant in the palisade region.

The characters most useful in distinguishing *Peronospora destructor* from closely related forms are, in order of merit: the large pyriform sporangia, the filamentous haustoria, the monopodial branching of the sporangiophores, and the germination of the sporangia by germ tubes.

The possibility exists that there are different strains or even species of the onion-downy-mildew organism, and that this explains the large differences in the organism as observed by different investigators. Hiura (26) has suggested the existence of strains on the basis of limited host-range studies, but the settling of this point must await comparative cultural studies of various collections of onion mildew.

ATTEMPTS TO CULTURE PERONOSPORA DESTRUCTOR ON ARTIFICIAL MEDIA

L. R. Jones (30) reported that attempts to grow the onion-mildew fungus on artificial media were unsuccessful, but he gives no details. McKay (36), using oöspores of which the germination had been stimulated by dilute potassium permanganate, reported that the total length of hyphae from oöspores in water varied from 2 to 8 mm in 3 days, and from oöspores on potato dextrose agar plus onion sap varied from 4 to 10 mm in 48 hours. The longest growth recorded by McKay was 15 mm in 6 days. McKay gives only few details of these tests and does not indicate that the potassium permanganate increased the length of the germ tubes apart from its effect in stimulating germination.

I have attempted in 180 tests with an average of 14 plates of different treatments per test to culture *Peronospora destructor* in liquid and agar media, but without success. Many treatments have given stimulation of the growth of the germ tubes, however.

Treatments Used.—In most of these studies, the test materials in solution or suspension were added separately to sterile petri dishes, and 15 cc of melted 1.7 per cent washed plain agar were added and mixed with the test materials. After the poured plates had cooled, they were placed in the bottom of a large galvanized can and seeded lightly by dusting them with fresh sporangia of onion mildew from greenhouse cultures usually at from 10 a.m. to 12 m., and incubated at 16° or 19° C in the dark for 2 to 4 days. Most culture studies were made in the winter and spring months. The cultures in liquid media were handled similarly except that agar was omitted. Sixty-seven different nutrient substances were tested separately and in various combinations in the agar cultures, and 5 in the liquid media. In evaluating the results, 10 germ tubes on each plate were selected at random and measured with an eyepiece micrometer.

The relatively pure test chemicals added to plain agar to determine their effect on the growth of *Peronospora destructor* were as follows: KMnO_4 , KOH , KNO_3 , KClO_4 , $\text{K}_2\text{S}_2\text{O}_8$, K_2HPO_4 , KCl , HCl , HNO_3 , H_3BO_3 , H_2O_2 , MnO_2 , MgSO_4 , Na_2HPO_4 , CaCO_3 , Barnes' mineral nutrient mixture (54), microelement mixture A (27), microelement

mixture B (27), sucrose, dextrose, mannitol, asparagine, *dl*-alanine, cysteine hydrochloride, glycine, glutathion, nucleic acid, tyrosine, hippuric acid, leucine, malonic acid, edestin, tryptamine hydrochloride, choline hydrochloride, salicin, arbutin, tryptophane, heterauxin, indole acetic acid, nicotinic acid, pimelic acid, carotene, riboflavin, wound hormone, vitamin A, vitamin B₁, vitamin C, phenol, potassium pyrogallate, paraffin oil, potassium acid phthalate, and brown sugar.

The extracts tested were of potato, lima bean, yeast, mycelium cultures of *Phytophthora citrophthora* (S. and S.) Leonian, germ-tube cultures of *Peronospora destructor*, mycelium cultures of *Rhizopus nigricans* Ehr., onion leaves, onion bulbs, rabbit liver, rabbit spleen, rabbit blood, rabbit kidney, egg yolk, and orange juice. The above test sources of growth-stimulating substances were mostly extracted in water at room temperatures, but the potato and lima-bean extracts were prepared with heat. Extracts of *Phytophthora*, *Rhizopus*, and *Peronospora* cultures were made under a variety of temperature conditions and with a variety of extractives. All pure materials and extracts were used in various amounts and combinations and all were used well below any apparent toxic level, as judged from the earlier tests. The pure materials were usually sterilized in solution with heat before use, but the extracts except potato and lima bean were unsterilized and were used immediately or held at 0° C.

With the exception of potassium permanganate, most of the test materials increased the amount of contamination on the plates. Only ordinary precautions were taken to avoid contamination, and contaminants were introduced from the greenhouse with the inoculum, from the laboratory air, and from the test chemicals. A few contaminants were usually present in the cultures, but as growth of *Peronospora destructor* had usually stopped before the contaminants had made any considerable growth, they were not considered of importance in the 4-day period that most of these cultures were kept.

Nature of the Growth.—On plain agar, germination of fresh sporangia usually varied from 30 to 100 per cent, and poor germination of the controls was never a limiting factor in these tests. Usually only 1 germ tube was formed by each sporangium, but occasionally 2 were formed. The germ tubes rarely branched. Growth was mainly on the surface of the agar, but some germ tubes grew down into the agar. Growth continued for about 2 days, and in about 4 days death of the germ tubes was indicated by the disorganized and beaded condition of the protoplasm of the germ tubes. On agar the germ tubes were fairly straight and easily measured, whereas in water they frequently grew in coils and were difficult to measure.

None of the treatments markedly increased the number of sporangia germinating or the number of germ tubes per sporangium, though many increased the branching. Some materials stimulated the formation of short side branches which bore a resemblance to haustoria and which were smaller in diameter than the main germ tubes. Some treatments caused the germ tubes to grow down into the agar to a greater extent than occurred on plain agar.

The most striking effects of the stimulatory treatments, however, were to increase the length and period of viability of the germ tubes. The longest germ tube observed was $3,880\mu$ on a medium consisting of 15 cc water, 1 cc lima-bean decoction, 250 mg agar, 1 mg KMnO_4 , 2 mg KNO_3 , 200 mg sucrose, 0.1 mg glutathion, 0.1 mg vitamin C, and 0.003 mg riboflavin. No strong significance is attached to this mixture for in this trial several other media yielded germ tubes almost as long. The longest period of life of the germ tubes was 6 days, also secured with the above mixture. No septation of the mycelium or formation of chlamydospore-like structures, as described by McKay (36), were observed in these cultures.

Variability of Germ-Tube Length.—In 4 tests selected at random, the coefficient of variability of germ-tube length as determined from 10 measurements on plain agar varied from 20 to 33 per cent, with an average of 28 per cent. The variability was about the same on other media. While this variability may be high in absolute terms, it is a great deal less than the variability of the germ tubes from the conidia of several powdery mildews as observed in similar culture tests.

Rate of Growth of Germ Tubes.—Katterfeld (31) and Cook (12) have reported that the germ tubes of the sporangia of *Peronospora destructor* grew at the rate of about 100μ per hour in water. A similar rate of growth of germ tubes from oöspores may be inferred from data of McKay (36). This is a more rapid rate than I have observed in agar cultures. Results of 2 tests are given in table 5. While these tests were not continued to show the time at which growth stopped, the final values for each test reported are about the maximum for the conditions specified, and only in 2 cases in other tests was an average growth of over $1,210\mu$ secured on plain agar. According to these results the maximum rate of growth, occurring between 8 and 27 hours after seeding, was about 50μ per hour, and the average was considerably less.

Amount of Stimulation.—In 74 tests on different days in which the growth on plain agar was compared with the growth on plain agar to which various substances had been added, the minimum average growth of 10 random germ tubes on 1.7 per cent plain agar was 273μ , the maximum was $1,603\mu$ and the average was 824μ . In the first 10 of these tests,

the average growth secured on the best medium in each test was 49 per cent greater than the growth secured on plain agar; in the last 10 tests, the average increase was 216 per cent, which indicates that in spite of the great variability between cultures and the small absolute amount of growth, some progress was made in the development of better agar media (p. 625).

Effect of Various Media on Growth.—In 7 tests in which potato dextrose agar was compared with plain agar, the growth on the latter varied

TABLE 5
RATE OF GROWTH OF GERM TUBES OF *Peronospora destructor* ON AGAR

Time after seeding	Test 1, 13° C, 1.7 per cent plain agar		Test 2, 13° C, 15 cc 1.7 per cent plain agar + 0.5 cc potato dextrose broth + 0.05 cc 1 per cent KMnO ₄ + 0.5 cc of a melted agar plate culture of <i>Phytophthora citrophthora</i>	
	Average length of germ tubes*	Rate of growth per hour in previous interval	Average* length of germ tubes	Rate of growth per hour in previous interval
<i>hours</i>	<i>μ</i>	<i>μ</i>	<i>μ</i>	<i>μ</i>
4.....	72	18	.....	..
6.....	136	32	.....	..
8.....	177	20	.....	..
10.....	292	57	.....	..
16.....	.....	..	510	32
21.....	852	51	.....	..
26.....	916	13	.....	..
27.....	.....	..	1,073	51
39.....	.....	..	1,198	10
41.....	1,210	20	.....	..
51.....	.....	..	1,350	13
63.....	.....	..	1,620	22

* Ten measurements averaged for each value given.

from 546 to 1,603 μ with an average of 1,040 μ , and on potato dextrose agar the growth varied from 0 to 555 μ with an average of 291 μ , which indicates that nutrients in potato dextrose agar were reducing growth. The addition of potassium permanganate increased the growth on nearly all agar media tested, and the increase was usually proportional to the content of organic matter. This is illustrated by the results of one test presented in table 6. Here increasing amounts of potato dextrose broth progressively decreased the amount of growth, and the addition of potassium permanganate was progressively more stimulatory as the amount of potato dextrose was increased. The most striking example of this was when potassium permanganate was added to cultures containing an extract from *Rhizopus* cultures. In 1 test, 0.1 cc of a melted, 4-day old *Rhizopus* culture added to 15 cc of plain agar totally inhibited the

growth of *Peronospora destructor*, but the addition of 0.1 cc of 1 per cent potassium permanganate to the plain agar plus *Rhizopus* extract resulted in an average of 1,935 μ for the germ tubes. Potassium permanganate was the most consistently stimulatory substance used in these tests.

Other materials which were stimulatory when added to plain agar plus potassium permanganate in numerous tests were glycine, potato dextrose broth, asparagine, riboflavin, potassium nitrate, dibasic sodium phosphate, and melted-agar cultures of *Phytophthora citrophthora*. Sev-

TABLE 6
RELATION OF POTATO DEXTROSE AND POTASSIUM PERMANGANATE
TO GROWTH OF GERM TUBES OF *Peronospora destructor*

Amount of 1 per cent KMnO ₄ added to plain agar	Average length of germ tubes with various amounts of potato dextrose broth added to 15 cc plain agar			
	With 0.0 cc added	With 1.0 cc added	With 2.0 cc added	With 8.0 cc added
cc	μ	μ	μ	μ
0.0.....	864	899	581	264
0.1.....	986	1,085	1,008	855
0.2.....	...	....	924	900

eral mixtures were superior to the addition of any single material. The mixtures that were most stimulatory when added to 15 cc of plain agar plus 0.1 cc of 1 per cent potassium permanganate were: (a) 1 cc potato dextrose broth plus 1 cc 10 per cent glycine; (b) 1 cc potato dextrose broth plus 0.2 cc of 1 per cent potassium nitrate; and (c) 2 cc potato dextrose broth plus 1 cc 10 per cent glycine plus 3 cc 10 per cent sucrose plus 0.1 cc 10 per cent dibasic sodium phosphate.

In the foregoing attempts to culture *Peronospora destructor* the possible toxicity of the agar itself was not considered. In 2 tests, germ tubes on 1.7 per cent agar averaged 326 μ , on 0.5 per cent agar averaged 633 μ , and on 0.2 per cent agar averaged 842 μ . Even this value, however, for 0.2 per cent agar is lower than that secured on 1.7 per cent agar in many other tests. Probably there are important differences between different lots of agar, but in 1 test where 2 lots of agar were compared, no marked difference was apparent, and the matter was not investigated further.

An attempt was made to continue the studies on liquid media, but some of the substances, including potassium permanganate, which were stimulatory on agar media, were highly toxic at the same concentration in water.

Some of the instances of apparent stimulation reported may be due to the effect of the test substances in reducing the toxicity of the agar.

In 3 experiments, however, the average and maximum growths in water cultures were less than in agar cultures. Liquid cultures are more difficult to use in such a study for several other reasons, such as the rapid spread of contaminants, and the difficulties of measurement of the germ tubes.

Effect of Host Extracts.—Strips of onion leaves with the internal surface exposed but otherwise uninjured were laid on the surface of seeded plates of plain agar. The spores under and immediately adjacent to the strips did not germinate, but those a few millimeters away germinated normally. Cold-water extracts of onion leaves prepared by grinding onion leaves in 5 times their weight of water and pressing the extract through gauze were poured over the surface of agar and the surplus poured off. Spores seeded on these plates did not germinate. Excised onion leaves were placed on the surface of plain agar and heated for 10 minutes at 90° C and the leaves removed. Spores seeded on this agar surface did not germinate. Apparently some substances are present in the onion-leaf extracts in concentrations toxic to the onion-mildew organism.

The explanation of this apparent anomaly is probably that under natural conditions the parasite does not come in contact with these materials. A variety of more dilute host extracts, however, were apparently stimulatory. In 1 test, 1 part of uncrushed leaves in 20 parts of water was heated for 2 minutes at 100° C and various amounts of the extract added to plain agar. Another extract was prepared by grinding 1 part of leaves in 20 parts of water and using the supernatant liquid after centrifuging. In this test, the germ tubes in the plain agar check averaged 740 μ , those cultures with 0.1 cc, 1.0 cc, and 5.0 cc of the extract from crushed leaves averaged 1,004 μ , 678 μ , and 0 μ , respectively.

Effect of Rate of Seeding.—In 1 test, sporangia seeded on plain agar at 0.31 sporangia per sq. mm, 2.3 per sq. mm, and 10.0 per sq. mm, and incubated 48 hours at 13° C gave average germ-tube lengths of 616 μ , 974 μ , and 1,069 μ , respectively, which indicate that heavy seeding favors growth of the germ tubes. The germ tubes from well-isolated single spores grew fairly well, however, and in practice the use of rather light seedings was found desirable for reducing contamination and for securing well-isolated germ tubes that could be easily measured.

Effect of Time of Day and Season.—Seeding of agar plates was generally performed at about 11 a.m. with sporangia produced during the previous night, but sporangia were transferred from sporulating plants to agar at various times of the day and night, and tests were conducted during all months of the year. No diurnal or seasonal variations in the amount of growth from sporangia was apparent. Sporangia 3 days old,

however, showed a lower percentage of germination and a smaller length of germ tubes than those used the morning after sporulation.

Effect of Temperature, Humidity, Light, Oxygen, Carbon Dioxide.—Most of the culture tests were conducted at 19° C, at which temperature the best growth occurred in 1 temperature test. In 2 tests, however, there was good growth with little difference in amount from 10° C (no lower tested) to 19° C with a marked reduction at 22° C and only a trace at 25° C. Exposure of the agar cultures over increasing concentrations of sulfuric acid to reduce the relative humidity decreased the amount of growth in 1 test. Exposure to natural and artificial light reduced the amount of growth slightly in 1 test. In 2 tests, exposure of the cultures over 10 per cent pyrogallol in 45 per cent potassium hydroxide, or over charcoal had no apparent effect on growth.

Adaptation to Agar.—In a series of tests it was attempted to determine if *Peronospora destructor* could be adapted to agar. The idea was that those sporangia which grew best and remained viable for the longest period would be reproduced, and possibly a strain established which was adapted to agar culture. Blocks of seeded agar from plates of test media were used to inoculate onion leaves after specified periods of growth on the agar. Sporangia produced on the onion leaves which were infected by this process were used to seed agar media again. After four generations of this process the selected and original onion-mildew cultures were compared, on the same test media, and no difference in the growth on agar was apparent.

OTHER FUNGI ACCOMPANYING DOWNY MILDEW ON ONIONS

Botrytis cinerea, *B. allii*, and *Macrosporium* sp. have been frequently observed on plants used in these studies. *B. cinerea* was found fruiting on dead onion leaves in the field and on dead leaves of greenhouse plants that had been incubated overnight in moist chambers. In greenhouse studies, mildew-inoculated leaves with dead tips have frequently given rise to sporulation of *Peronospora destructor* on the living portion of the leaf and to *B. cinerea*^{*} on the dead portion. Inoculation with a spore suspension of *Botrytis* from these infected leaves gave rise to elongate, depressed white spots on onion leaves in the greenhouse in 3 days. Such lesions showed no sporulation when the infected plants were incubated in a moist chamber, but after several days such leaves frequently died, and on the dead leaves an abundant sporulation of *Botrytis* occurred in moist chambers. In field plantings a similar white spotting has been observed on onion leaves, and on occasions this spot-

* The fungus *Botrytis cinerea* was grown in culture and identified by Dr. H. N. Hansen.

ting (fig. 4) and the killing of the leaves following it, has caused losses in onions grown for greens at Bay Farm Island and San Pablo.

*Botrytis allii*⁷ has not been observed causing localized injury to leaves but is sometimes destructive to seedstalks and entire plants. The characteristic symptoms and signs are a paling of the seedstalks, followed by the formation of concentric arcs or rings of sporodochia or sclerotia. Infection apparently usually starts at the base of the seedstalk and extends upward, but the apparent starting in the flower head and working downward is not uncommon. Seedstalks infected with *B. allii* usually produce very little seed, and in this sense it is more destructive

TABLE 7

DISTRIBUTION OF *Macrosporium* LESIONS ON AUSTRALIAN BROWN ONION SEEDSTALKS, MILPITAS, AUGUST 12, 1937

Treatment	Seedstalks showing no <i>Macrosporium</i>	Seedstalks showing <i>Macrosporium</i>		
		On all sides	On south side only	On north side only
Control, no treatment (2 plots).....	number 9	number 163	number 0	number 106
Sprayed April 24, 30, May 7, 14, 21, 28 with 2 per cent rosin lime-sulfur (2 plots).....	325	3	1	58

than *Peronospora destructor*, for a seedstalk infected with the latter may sometimes have several downy-mildew lesions and yet produce a fair yield of seed. *B. allii* was serious in experimental plantings at Berkeley in 1937 and 1938, and has been observed at Milpitas, San Pablo, and Cotati, but not in the large plantings in the Sacramento-San-Joaquin Delta region or in the southern portion of the Santa Clara Valley. A brief report of *B. allii* and *B. cinerea* on onions has already appeared (81).

Infection with *Macrosporium* has followed that with downy mildew on onion leaves and seedstalks in the field each year from 1935 to 1940, though I have not observed *Macrosporium* on leaves or seedstalks not already infected with downy mildew. Spores of great variability were found on these lesions. Results of one set of observations, presented in table 7, show that spraying with 2 per cent rosin lime-sulfur gave better control of *Macrosporium* than of downy mildew (see also tables 27, 28) and that *Macrosporium* lesions occurred in greatest abundance on the north side of the seedstalks. This is possibly because infection with *Macrosporium* requires a long period with moisture on the seedstalks, and the rain or dewdrops remained for a longer period on the north side.

⁷ The fungus *Botrytis allii* was also cultured and identified by Dr. H. N. Hansen.

CARRYOVER OF ONION MILDEW FROM ONE SEASON TO ANOTHER

The manner in which onion downy mildew lies dormant during periods of inactivity of the host, and by means of which it is carried over from one crop to a succeeding one has been subjected to considerable speculation and experimental study. Because of differences in climate and manner of onion culture, this seasonal perpetuation consists in overwintering in some regions of cold winters as in New York, of over-summering in some regions of mild winters and dry, warm summers as in California, and of overwintering and oversummering as reported by Katterfeld (31) in Russia. The methods of carryover which should be considered are: (a) carryover as mycelium in the bulbs, seed, or soil, (b) carryover as oöspores on or in seeds, or in the soil or refuse, (c) seasonal reintroduction by wind or other agencies from an infected region to a noninfected crop.

CARRYOVER AS MYCELIUM .

Carryover of onion downy mildew as mycelium in dormant bulbs was suggested by Trelease (69) and Dudley (16), but was first established by Murphy (43) in Ireland in 1921.

On march 15, 1935, at Cotati, 1 plant with small, pale, down-curved, heavily sporulating leaves was observed in a field of late-planted onions showing considerable secondary downy-mildew infection. A total of 1,000 plants was then examined but no more such plants were found. The stunted development of this plant indicates that it probably grew from a systemically infected mother bulb. The possibility that it became infected after planting in the field is not excluded, but is unlikely since no other similarly infected plants could be found.

On February 25, 1935, a group of bulbs from a heavily infected 1934 crop of bulbs grown at Davis were planted in the greenhouse at Berkeley. Of 4 of the Sweet Spanish and 9 of Australian Brown which grew by March 17, only 1 of the Sweet Spanish plants showed symptoms of infection, and this plant produced an abundance of sporophores on overnight incubation in a moist chamber.

On March 25, 1937, most of one day was spent in carefully examining random areas in several hundred acres of onions of numerous varieties grown for seed in various locations in the Santa Clara Valley. In none of these fields was any secondary mildew infection found, and only 1 systemically infected plant—and this without sporulation—was found.

On August 25, 1938, bulbs of 3 strains of Yellow Bermuda, 1 of Red Creole, and 1 of Early Grano, all from a heavily infected bulb crop

grown at Milpitas in 1937-38, were planted in Berkeley outdoors. These varieties were chosen because they were among the most severely infected in a block of several varieties, the leaves of which were killed by mildew. On October 4, the plants grown from this heavily infected bulb crop showed no secondary mildew infection and only 5 systemically infected plants; 3 of the latter are illustrated in figure 2.

On October 19, 1938, other lots of plants grown from bulbs from these heavily infected 1937-38 Milpitas fields were examined at Milpitas. Seven systemically infected plants were found among 1,674 Stockton Yellow Globe plants, but no systemic infection was found in 226 Lord Howe Island plants or in 244 plants of Early Grano. The scarcity of systemic infection in bulbs from plants known to be heavily infected, emphasizes the relatively small amount of carryover as systemically infected bulbs in California.

In addition to the detailed observations already given, many thousands of onion plants grown for seed in 1935-1940 were examined for evidence of carryover of the disease in dormant bulbs and none were found, though many of the mother bulbs were known to come from crops showing mild to severe mildew infection. If my observations and conclusions are correct, the situation in California is in marked contrast to the condition in Ireland (44) where as high as 100 per cent infection has been found in dormant bulbs.

While systemically infected bulbs apparently responsible for the oversummering of onion mildew in California are rare, systemically infected field plants are less rare. On May 24, 1935, all plants of a block of Red Wethersfield grown for bulbs on Liberty Island were systemically infected, but no other variety showed severe systemic or secondary infection. Twenty of the Red Wethersfield plants were dug up and potted in Berkeley. Only 2 survived; these were weak and no sporulation could be induced on them. On January 12, 1938, a plot of Yellow Bermuda grown for seed at Milpitas was examined and no systemic infection was noted, though there was considerable local infection on the leaves. On March 21, 104 out of a total of 717 of these same plants showed systemic infection. I believe that this systemic infection occurred after the bulbs were planted and did not originate from dormant mycelium in the bulbs. On March 14, 1939, a field of plants grown for bulbs at Salinas showed 36 plants with systemic infection out of 100 counted.

In the early stages of this study, tissues from several bulbs from crops known to be heavily infested with mildew were examined microscopically but no downy-mildew mycelium was found. This is not surprising in view of the scarcity of naturally occurring systemically infected plants resulting from an infected bulb crop. In plants showing

systemic infection, however, downy-mildew mycelium could be found continuous from the leaves to the growing plate at the base of the bulb in all cases. While detection of the fungus in the dormant bulbs as was done by Murphy and McKay (44) is desirable evidence that they are actually infected, I consider the production of systemically infected plants from dormant bulbs under conditions that preclude infection from other sources to be good evidence that the bulbs were systemically infected and could serve to carry over the disease. Mildew mycelium has been found in dormant bulbs several days after artificially inoculating them with a spore suspension, but in only small amounts.

An attempt was made to determine the factors underlying the occurrence of systemic infections, but without success. Systemic infection occasionally developed on plants grown in the greenhouse from healthy bulbs inoculated by spraying the healthy leaves with a spore suspension, but the number of plants systemically infected under these conditions seemed too low to use this method for further study. On seedling plants, however, a high percentage of systemic infection frequently developed, and inoculated seedling plants were subjected to various light, temperature, and leaf-pruning treatments without apparently significant differences in the incidence of systemic infection. Since systemic infection appeared to occur more frequently in the winter months in field and greenhouse plantings, however, I believe that slow rate of growth of the onions or low temperatures are favorable for the occurrence of systemic infection.

In the field of Stockton Yellow Globe at Milpitas in 1938-39, all plants showing systemic infection were staked on November 7, 1938. On February 20, 1939, at which time there was considerable sporulation and secondary infection, a few systemically infected plants were found in addition to those already staked. As these unstaked, systemically infected plants were larger than the staked plants and had shown no symptoms on November 7, I believe that these plants were infected after November 7. On February 20, some of the systemically infected plants staked on November 7 were dead, and the bulbs decayed. The comparative appearance on February 21 of plants without systemic infection, those which showed systemic infection on November 7, and those on which systemic infection showed up later is illustrated in figure 1.

SEED TRANSMISSION NOT DEMONSTRATED

Onion downy mildew might be carried over in the seed as viable mycelium or oöspores in the seed or as oöspores on the seed. Katterfeld (31) found mycelium and oöspores in the pedicels of the flowers and almost reaching the base of the ovary but could not find mycelium in

the seed. He believed that mycelium could not enter the pedicels if infection occurred after the formation of the seedstalks. Hiura (25) found mycelium in the flower stalks, perianths, styles, ovaries, filaments, and anthers, but not in the ovules. Cook (12) found mycelium in the ovules. Chapman (9) found onion-mildew spores, presumably oöspores, in 10 out of 10 lots of onion seed. Cook found a few oöspores in several lots of onion seed. Katterfeld (31), Murphy and McKay (44), and Hiura (25), however, obtained only healthy plants from seed from mildew-infected plants. Field observations have been used as evidence of seed transmission. Newhall (47) states, "There is also evidence in many fields that seed was in several cases responsible for initial infection this year as blight appeared as early and spread as rapidly on muck growing its first crop of onions as on old onion soil." Later Newhall (49) made extensive tests of seed treatment as a means of onion-mildew control, but reported no apparent success.

To determine the possibility of seed infection in California, seed from the variety Prizetaker was saved in 1935 from 12 seedstalks with mildew infection just below the head. Most of the seed was shriveled, but 440 seeds grew and no mildewed seedlings resulted from this seed. Bulk seed from the same heavily mildewed crop also showed no infection in the resulting seedlings. In another test, green healthy seed heads on field plants were inoculated on August 6, 1935, by spraying them with a spore suspension and incubating them overnight in moist chambers. From these inoculated heads, 343 seeds grew and none of the plants showed infection. I feel that there is no good evidence that onion mildew may be carried over from one season to another with the seed.

Spread by Oöspores.—Jones (30) scattered oöspore-bearing refuse from mildewed onions on a greenhouse plot and planted this and a control plot with onion seed in December. In April, mildew appeared in the plot in which refuse had been placed but not in the control plot. Murphy and McKay failed to get infection from refuse from mildewed onions in tests reported in 1926 (45) but in 1932 they reported that naturally contaminated soil freely conveyed the disease to seedling onions.

Germination of an oöspore of onion mildew was first reported by Murphy and McKay (46). They reported that a 6-month-old oöspore which had wintered in the laboratory produced a slender hyphal thread bearing about 24 conidia on short, irregularly arranged branches. In later, more extensive tests, McKay (36) reported that germination of oöspores occurred by means of germ tubes, and only with oöspores four years or more in age. In spite of the small amount of evidence, oöspores must be recognized as a potential source of primary infection of onion downy mildew.

Spread by Sporangia.—Doran (14) has given circumstantial evidence that infection of cantaloupe downy mildew in the northeastern United States may arise from air-borne sporangia produced on plants farther south. A similar situation is possible with onion downy mildew. In the San Francisco Bay region, specifically in the Colma and Bay Farm Island districts, onions are grown for greens throughout the year, and downy mildew has been found in these districts at all seasons. As the principal seed-producing areas are within 100 miles of this region, as the prevailing winds are principally west, southwest, and northwest from the Bay region (5), and as sporangia are viable for several days, the opportunity for sporangia from the Bay region to cause infection of onions grown at Cotati, in the Sacramento-San-Joaquin Delta region, and in the Santa Clara Valley appears good.

Of the four principal methods by which onion mildew might originate, namely, (1) systemic mycelium in the bulbs, (2) oöspores in soil or refuse, (3) sporangia from regions where onion mildew prevails throughout the year, and (4) infected seed, I believe the first is of greatest importance in California, the second two are of minor importance, and the fourth is of very little importance or nonexistent.

FACTORS AFFECTING FORMATION OF SPORANGIA

Sporangiophores and sporangia of onion downy mildew are normally formed on leaves and seedstalks under conditions of high humidity at night. Conditions governing sporulation might be divided into those preceding and those during sporulation. According to my conception of the diurnal cycle of sporulation (79), the host tissues must build up during the light portion of the day a reserve of labile materials necessary for sporulation. Although under natural conditions light is probably never a limiting factor in this process, nevertheless, under controlled conditions infected greenhouse plants sporulated best when transferred to dark, moist chambers at 4 p.m. to 10 p.m. and sporulated poorly or not at all when transferred to dark, moist chambers at 12 p.m. to 1 a.m. Also plants held in a dry, dark environment for 24, 36, or 48 hours could not be induced to sporulate by placing them in dark, moist chambers at 13° C, but sporulation was made possible by exposing them to light for a few hours. These facts are in accordance with the theory that food reserves are necessary to sporulation. Attempts to show that the labile product necessary for sporulation was sucrose were not successful. Infected leaves that had been held in the dark were placed with their bases in 5 per cent sucrose or floated on 10 per cent sucrose in the dark for various times, but these treatments did not induce sporulation. Also excised leaves from plants that had been held in

the dark were exposed to light in sealed chambers containing an excess of potassium hydroxide to remove carbon dioxide and reduce photosynthesis, and these leaves showed sporulation after being placed in dark, moist chambers.

No data under controlled conditions of the effect of temperature during the light portion of the day on the subsequent sporulation at night have been secured, but I believe that high temperatures during the day are sometimes responsible for poor sporulation the following night. In the first clear warm days of spring, before the greenhouses were whitewashed to reduce the temperature, it was not uncommon for the greenhouse air temperatures to go up to 35° and 48° C for short periods and to fall to 12° to 18° C at night. On several such occasions mildewed onions have failed to sporulate in moist chambers at night; this was no doubt due to the high temperature during the light portion of the day, which is probably also sometimes responsible for failure of sporulation under field conditions. With greenhouse day temperatures probably never going below 18° C, low day temperature has apparently never been responsible for sporulation failures, but under field conditions in winter when sporulation is very erratic, low day temperatures might be responsible for the failure of subsequent sporulation in some cases.

Humidity, temperature, and light are the principal factors acting during sporulation to determine its success. Under greenhouse conditions, with the observed relative humidity at night varying from 65 to 81 per cent, onion mildew rarely sporulated, though luxuriant sporulation occurred at similar temperatures when the plants were incubated overnight in moist chambers. Low humidity is apparently also frequently responsible for the failure of infected plants to sporulate under field conditions. To determine more accurately the effect of humidity on sporulation, onion leaf tissues with their bases in cotton-stoppered vials of water were placed in sealed chambers containing water or dilute sulfuric acid to produce specified relative humidities (63). Sporulation was rated on an arbitrary relative scale of 0 to 10, in which 0 indicated no sporulation and 10 indicated luxuriant sporulation. Results of 3 tests at 16° C were as follows:

Relative humidity, in per cent	December 18, 1935, sporu- lation rating	December 20, 1935, sporu- lation rating	January 7, 1936, sporu- lation rating
100.....	10	10	10
97.....	10	5	5
94.....	10	1	0
90.....	5	0	0
80.....	0	0	0

These results indicate an optimum of about 100 per cent relative humidity for sporulation, with a minimum of about 90 per cent.

Humidity is apparently an important factor in determining the size of the sporangiophores, though no data were collected from controlled tests. On the morning of March 29, 1937, some plants exposed on the greenhouse bench showed considerable sporulation, though not so much as similar plants incubated overnight in a moist chamber at the same temperature. From mounts of the sporangiophores produced on each

TABLE 8
EFFECT OF TEMPERATURE ON SPOULATION* OF ONION DOWNY MILDEW

Temperature ° C	Excised leaves		Potted plants		Average rating
	5 p.m. December 18, 1935	8 p.m. July 6, 1937	5 p.m. February 10, 1939	6 p.m. February 23, 1939	
4.....	0	0.0	.	0.0	0.0
7.....	0	0.0	2.0	5.7	1.9
10.....	8	5.1	4.9	6.0	5.7
13.....	10	...	9.0	7.1	8.7
16.....	5	7.9	8.0	6.7	6.9
19.....	6	0.2	1.3	0.2	1.9
22.....	3	0.1	1.1	3.7	1.9
25.....	0	0.0	0.0	0.0	0.0
28.....	0	...	.	...	0.0

* Scale of 0 (no sporulation) to 10 (luxuriant sporulation).

set of plants, the length of 10 random sporangiophores was determined. Those produced in the open greenhouse ranged from 122μ to 167μ and averaged 150μ ; those from the moist chamber ranged from 317μ to 828μ and averaged 521μ .

To determine the effect of temperature on sporulation, potted plants or pieces of onion leaves were transferred to moist chambers and held at various temperatures in the dark. Results of 2 tests with excised leaves and 2 with potted plants are given in table 8. The results indicate a minimum temperature for sporulation of 4° to 7° C, an optimum of about 13° C and a maximum of 22° to 25° C. The temperature range for sporulation is therefore lower than that for germination and infection.

Temperatures prevailing during sporulation affect the size of the sporangiophores. In 2 tests, summarized in table 9, the sporangiophores averaged 324μ at 7° C, 593μ at 16° C, and 480μ at 22° C. From the data of table 9 there is no apparent consistent effect of temperature on size of sporangia, but these data are probably inadequate.

Sporulation of onion mildew in daylight has not been observed to occur, and infected greenhouse plants placed at 8 to 10 a.m. in moist

chambers exposed to daylight of cloudy days have failed to show sporulation by 5 p.m. on several occasions. In 3 out of 6 tests, however, sporulation occurred in artificial light at night. In these tests excised leaves were placed at 21° C in a sealed glass moist chamber immersed in a water bath and exposed at a distance of 6 cm or more to a 150-watt Mazda lamp giving from 160 to 1,000 foot-candles of light on the leaf surface. Control leaves were placed in darkness at 22° C, a temperature far above the optimum for sporulation but under which conditions fairly satisfactory sporulation occurred in these tests. In 5 of the 6 tests, sporulation occurred on the control leaves and in 4 of the 5 successful

TABLE 9
EFFECT OF TEMPERATURE ON SIZE* OF SPORANGIOPHORES AND SPORANGIA

Temperature ° C	Test of February 11, 1939			Test of February 24, 1939	
	Length of sporangiphores	Length of sporangia	Diameter of sporangia	Length of sporangiphores	Length of sporangia
4	0	0	0	0	0
7	284	65	27	384	60
10	299	58	26	448	63
13	459	54	23	600	58
16	554	63	24	632	55
19	320	51	22	431	51
22	412	56	21	548	64
25	0	0	0	0	0

* Each value is the average of 10 measurements.

tests the sporulation was slightly more luxuriant in darkness than in light, but in 1 test the sporulation was apparently more successful in light. Sporangia formed under these conditions of artificial light at night were abnormal in shape in that they were frequently constricted in the center. From these tests of the effect of light before and during sporulation, it appears that exposure of infected plants to light favors subsequent sporulation in darkness, that during sporulation light is unfavorable to the sporulation process, and that the normal diurnal cycle of sporulation of onion mildew in nature is in part an adaptation to the alternation of light and darkness in the normal day.

In 2 tests the epidermis was peeled from portions of infected leaves, and the leaves were opened to expose their inner surfaces, which normally face the inner cavity, before placing them in moist chambers. In both tests sporulation occurred on the surface from which the epidermis was removed, but it was estimated that only about one tenth as many sporangiphores were formed on this surface as on the normal surface. Sporulation did not occur on exposed or unexposed inner surfaces of the onion leaves.

MATURATION AND DISSEMINATION

At 8 p.m., April 14, 1936, infected plants were transferred from the dry greenhouse bench to moist chambers at 18° C. At 12 p.m. infected leaves showed an abundance of sporangiophore initials with occasional branching but with no sporangia. At 3 a.m., April 15, the sporangiophores were completely developed and the sporangia were about one third their mature size. At 6 a.m. the plants were returned to the dry greenhouse bench. The sporangia appeared mature, but were not readily released. At 7 a.m. the sporangia were readily released by shaking the leaves. The mechanics of sporangium release was not studied, but generally observations indicate that it is a passive phenomenon which depends on agitation of the leaves and on air currents. When sporulating leaves are removed from a moist chamber to a dry environment a slow turning of the sporangiophores, less pronounced than with hop downy mildew, is apparent, but this movement does not appear very effective in discharging the sporangia.

The liberation of sporangia from sporulating plants was followed by periodically changed spore-trap slides in 3 tests. At 8 a.m., December 12, 1935, a heavily mildewed plant with a fresh first crop of sporangiophores was transferred from a moist chamber to the dry greenhouse bench and one slide was placed on the bench on each of two opposite sides of the plant. In the interval from 8 a.m. to 10 a.m., 2 sporangia were found on 3.2 sq. cm of area on the slides; from 10 a.m. to 12 m., 30 sporangia; from 12 m. to 3 p.m., 166 sporangia; and from 3 p.m. to 6 p.m., 71 sporangia. The temperature and relative humidity were 14° C and 71 per cent, respectively, at 10 a.m. and 18° C, and 48 per cent at 3 p.m. From these results it would appear that maximum liberation of sporangia occurred between 12 m. and 3 p.m.

In another test, started at 7 p.m., June 14, 1936, 3 plants were placed in a dark moist chamber at 13° C and 6 in a light greenhouse moist chamber and slides were placed beside the plants. At 6 a.m., June 15, the plants were sporulating luxuriantly, and the sporangia appeared mature but none were collected on the slides. Three of the plants from the light greenhouse moist chamber were transferred to the dry greenhouse bench. At 8 a.m. a total of 37 sporangia were counted on 0.4 sq. cm on each of 3 slides beside plants in the dark moist chamber at 13° C, none on slides beside the plants in the greenhouse moist chamber, and 2 sporangia on the slides beside the plants on the greenhouse bench. At 2 p.m., 290 sporangia were counted on 1.2 sq. cm of slides beside the plants in the 13° C dark moist chamber, 10 on the slides beside the plants in the greenhouse moist chamber, and 377 on the slides on the greenhouse

bench. The high number of sporangia caught from plants in a dark moist chamber was unexpected, but the test was not repeated.

At 10:20 a.m., February 19, 1941, 9 spore-trap slides were exposed on the ground in various positions on all sides of a plot of onions showing fresh sporulation of onion mildew at Milpitas. At the end of each test

TABLE 10
LONGEVITY OF ONION-MILDEW SPORANGIA ATTACHED TO SPORANGIOPHORES ON
ORIGINAL SPORULATING LEAVES

Time of start of test*	Condition of exposure†	Period of exposure	Germination
		hours	per cent
11 a.m. January 24, 1936	Detached leaves, ‡ greenhouse	81	58
9 a.m. January 25, 1936	Detached leaves, ‡ greenhouse	56	91
8 a.m. March 14, 1936§	Normal	12	50
9 a.m. April 9, 1936	Normal	46	98
9 a.m. April 9, 1936	Normal	57	34
9 a.m. April 9, 1936	Detached leaves, ‡ outdoors	46	13
9 a.m. April 9, 1936	Detached leaves, ‡ outdoors	54	0
8 a.m. April 17, 1936	Normal	72	40
8 a.m. April 17, 1936	Normal	96	2
8 a.m. April 17, 1936	Normal	120	0
8 a.m. May 6, 1936	Greenhouse	5	50
8 a.m. May 6, 1936	Greenhouse	192	0
8 a.m. April 2, 1937	Normal	72	0
8 a.m. April 2, 1937	Greenhouse	72	86
8 a.m. April 2, 1937	Greenhouse	96	28
8 a.m. April 2, 1937	Greenhouse	144	18
8 a.m. April 2, 1937	Detached leaves, ‡ greenhouse	72	55
8 a.m. April 2, 1937	Detached leaves, ‡ greenhouse	96	0
9 a.m. April 6, 1937	Normal	24	83
9 a.m. April 6, 1937	Detached leaves, ‡ outdoors	24	1

* Time of removal from moist chamber of freshly sporulating plants which were later used as a source of sporangia.

† On turgid living leaves attached to potted plants outdoors unless otherwise mentioned.

‡ Leaves cut from sporulating plants and exposed in dry open petri dishes. Such leaves usually wilted in a few hours and became brittle in a few days.

§ Naturally sporulating field plants. The 8 a.m. time and 12-hour exposure period are approximations.

interval 0.4 sq. cm of each slide was examined for sporangia and a clean slide was exposed in the same position. The number of sporangia caught at the different positions varied with the prevailing wind and with the proximity to sporulating plants. For all slides and all positions, the number of onion-mildew sporangia per hour per sq. cm of slide was 57 from 10:20 to 10:45 a.m., 22 from 10:45 to 11:20 a.m.; 15 from 11:20 a.m. to 12:20 p.m.; 4.5 from 12:20 to 1:40 p.m.; 4.1 from 1:40 to 2:40 p.m.; and 3.2 from 2:40 to 3:35 p.m.

On the basis of these 3 limited tests, I believe that the maximum liberation of sporangia of onion mildew is a few hours after the sporangia are apparently morphologically mature and that the rate falls off progressively from around midday to the next maturation of spo-

rangia. Under greenhouse and field conditions, however, sporangio-phores and many sporangia may remain attached to the leaves for several days.

LONGEVITY OF SPORANGIA

The longevity of sporangia of onion mildew was measured in 16 tests, from which sample data are presented in tables 10 and 11. These tests were designed to simulate natural conditions, and to measure the longevity of sporangia when attached to the sporangiophores on turgid leaves,

TABLE 11

LONGEVITY OF ONION-MILDEW SPORANGIA ON DRY LEAVES OF HEALTHY PLANTS

Time of start of test*	Age of sporangia†	Condition of exposure of healthy plants seeded with sporangia	Period of exposure	Plants inoculated	Plants infected
	hours		hours	number	per cent
9 a.m. April 9, 1936	1	Outdoors	10	10	40
9 a.m. April 9, 1936	58	Outdoors	0	23	55
9 a.m. April 9, 1936	58	Outdoors	4	16	6
8 a.m. September 23, 1936	1	Greenhouse	0	15	73
8 a.m. September 23, 1936	1	Greenhouse	24	19	10
8 a.m. September 23, 1936	1	Greenhouse	72	19	0
8 a.m. September 23, 1936	1	Outdoors	72	15	13
8 a.m. April 27, 1937	8	Outdoors	3	66	42
8 a.m. April 27, 1937	8	Outdoors	28	117	0
8 a.m. May 25, 1937	13	Outdoors, sun	24	68	0
8 a.m. May 25, 1937	13	Outdoors, shade	24	71	31
8 a.m. May 25, 1937	13	Greenhouse, sun	24	64	41

* Time of removal from moist chamber of freshly sporulating plants which were later used as a source of sporangia.

† Age of sporangia is given as from the time when the sporulating plants were removed from the incubator to the time when the sporangia were dusted onto healthy plants.

when attached to the sporangiophores on dead leaves, and when detached and lying on the surface of healthy leaves. To accelerate the drying out and death of leaves, the test leaves bearing sporangiophores and sporangia were cut from plants and exposed in open petri dishes to the test environment. Germination tests were performed by seeding the test sporangia onto plates of plain agar, and after an adequate incubation period 100 sporangia were counted for each germination percentage recorded. To determine the percentage infection, the healthy plants seeded with sporangia were sprayed with water, placed overnight in a moist chamber, left on the greenhouse bench for 12 days, incubated in a moist chamber, and the number of plants showing sporulation was counted. In all but 2 of the tests, control sporangia taken at the time of removing the sporulating plants from the moist chambers germinated 90 per cent or above, and the low percentages in tables 10 and 11 must be attributed to the injury caused by the subsequent environment. With sporangia dusted onto plants, however, results were rather erratic, and

100 per cent infection was rarely secured. All tests were performed in the absence of rain but with no other selection of weather conditions. From the results of tables 10 and 11, it appears that the sporangia of onion mildew may live for 3 to 5 days on the sporangiophores of turgid leaves outdoors, but for a lesser period on detached wilted leaves, and as detached sporangia on healthy leaves in the outdoor environment in Berkeley. Another important epidemiological factor, the length of time the sporangia may remain viable while being disseminated by wind, was not studied, but Newhall (49) has reported that sporangia caught in the air up to 1,500 feet elevation were still viable.

TABLE 12

EFFECT OF TEMPERATURE ON GERMINATION OF SPORANGIA OF ONION DOWNY MILDEW

Temperature ° C	Germination in water substrate				Germination on agar substrate	
	4 p.m. Nov. 8, 1935	9 a.m. Nov. 23, 1935	4 p.m. Dec. 4, 1935	4 p.m. Dec. 6, 1935	5 p.m. Feb. 5, 1936	11 a.m. Apr. 27, 1936
	per cent	per cent	per cent	per cent	per cent	per cent
1.....	2	0	1	8	0	95
4.....	4	22	4	11	94	96
7.....	2	22	5	50	93	98
10.....	..	19	3	15	99	97
13.....	3	..	13	19	95	92
16.....	20	18	16	18	96	94
19.....	9	20	6	12	96	99
22.....	..	16	5	15	91	53
25.....	..	0	6	0	70	0
28.....	..	0	0	0	0	0

GERMINATION OF SPORANGIA

The sporangium of onion mildew germinates by the formation of a germ tube which usually arises from near the proximal, pointed end of the sporangium, and the germ tube is frequently constricted at the point of origin from the sporangium. To determine if free water was necessary for germination, sporangia were dusted onto slides on which drops of water had been placed, and the slides were incubated in petri-dish moist chambers at 16° C. After 16 hours the sporangia in and on the drops of water showed a high percentage of germination, but those on the dry glass beside the drops showed no germination.

With potted plants, however, as heavy infection was secured when dry plants were dusted with dry sporangia and placed overnight in a moist chamber at 13° C as when similarly inoculated plants were sprayed with water before being placed in the moist chamber (84).

The effect of temperature on the germination of sporangia was measured in 6 tests which are summarized in table 12. In the tests of Novem-

ber 8 to December 6, 1935, drops of spore suspension were placed on the slides; in the other 2 tests sporangia were dusted onto plates of plain agar. Germination counts of 100 sporangia per treatment were made about 18 hours after seeding. The results are not consistent but indicate that germination may occur from 1° C (no lower tested) to about 28° C, with no apparent difference in the amount of germination from 7° to 16° C. The high germination in some tests at 1° C is of interest.

TABLE 13
DISTRIBUTION OF DOWNY-MILDEW INFECTION IN ONION FIELDS AS RELATED
TO PREVAILING WIND*

Date and location	Plants infected				
	North side	East side	South side	West side	Center
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
April 22, 1935, San Pablo, field 1.....	51	98	48	2	46
April 22, 1935, San Pablo, field 2.....	..	100	..	0	..
April 23, 1935, Modesto.....	..	100	..	94	..
April 24, 1935, Cotati, field 1.....	24	88	78	62	..
April 24, 1935, Cotati, field 2.....	99	88	..	62	..
June 3, 1938, Cotati.....	27	..	3	..	..
April 22, 1938, Walnut Grove.....	10	38	25	7	36
April 29, 1938, West Sacramento.....	72	78	56	4	87
July 13, 1938, Cotati, field 1.....	2	1	14	3	..
July 13, 1938, Cotati, field 2.....	11	..	13	6	..
Bay Farm Island.....	..	76	..	0	..
Average.....	36	74	34	24	..

* Prevailing winds at these locations from west and south.

The effect of light on germination was measured in only 1 test. One dish of sporangia was exposed at about 13° C to about 100 foot-candles of light from a Mazda lamp and a similar mount was exposed to the dark. After 18 hours, germination in the light was 87 per cent and in the dark was 98 per cent. The germ tubes formed in the light were smaller in diameter and shorter than those formed in darkness.

SECONDARY CYCLES

Secondary cycles of onion mildew arise from sporangia disseminated through the air from plants with primary infection—usually systemic infection. I have never observed systemic infection to be the direct cause of serious losses in California; the widespread crop damage is caused by secondary infection. Systemically infected plants from bulbs planted for a seed crop have shown sporulation in October; and since sporangia may produce lesions ready to sporulate in about 10 days, many secondary cycles of the fungus may have occurred before the destructive

epidemics which usually occur in March, April, and May. Wind dissemination of the sporangia of onion downy mildew has been recorded by several investigators but Newhall (48) was perhaps the first to record the recovery of onion-mildew sporangia from the air on spore traps. Newhall records catching sporangia in air over onion fields to elevations of 1,500 feet.

The distribution of onion-mildew infection in several California fields afforded good circumstantial evidence of the wind-borne nature of the disease (table 13). In most cases, infection was heavier on the leeward side of onion fields with respect to the prevailing winds. After infection becomes severe, differences in different parts of the field may be no longer apparent. Table 13 records all cases where counts were made, but cases were seen where all plants were infected on all sides of the field.

INOCULATION AND INFECTION

Artificial Inoculation Methods.—In nature, inoculation probably occurs almost exclusively by the transfer of sporangia from a sporulating leaf to a healthy leaf by the agency of wind and minor air currents. In this study the following methods of inoculation have been tested:

1. Dusting dry sporangia onto dry or wet leaves or seedstalks.
2. Spraying a spore suspension onto leaves and seedstalks.
3. Applying a wet cotton swab containing sporangia to seedstalks.
4. Applying agar blocks containing sporangia to leaves and seedstalks.
5. Injection of a spore suspension into the internal cavity of leaves and seedstalks.
6. Injection of a spore suspension into dormant bulbs.
7. Inserting pieces of infected leaf tissues into dormant bulbs.

All methods were successful except the last.

Dry sporangia were used extensively as inoculum in tests on the effect of free moisture on infection with onion mildew and other fungi (84), and in inoculating field plots. The method as used in greenhouse cultures was to lay the healthy plants to be inoculated in the bottom of a large can and dust sporangia on them from above.

Spraying with a spore suspension was the most widely used method of inoculation in this study. In 10 consecutive fungicide tests from February 9 to June 12, 1936, the percentage infection of the control seedling plants inoculated by spraying with a spore suspension varied from 62 to 100 per cent, with an average of 88 per cent. Much better control and knowledge of the distribution of the inoculum is possible by using a spore suspension than by using dry sporangia; and an abundance of free moisture, believed desirable for the germination of the sporangia and for maintaining a high humidity, is provided with the inoculum. One

infected sporulating leaf can be used to inoculate hundreds of plants by this method.

Inoculation by applying a wet cotton swab containing sporangia was successfully used in 2 field tests on dry nights when individual seedstalks were to be inoculated without inoculating others. Strips of absorbent cotton about 3 inches long were dipped in a spore suspension and wrapped around the seedstalks.

Agar blocks containing sporangia were used in greenhouse tests where it was desired to inoculate leaves in a specific location, or where it was desired to test the infectivity of cultures growing on test agar media. Sporangia were dusted onto the cooled test agar plates, and small squares were cut from these plates and applied to the surface of onion leaves, to which they usually adhered if applied carefully.

The injection of a spore suspension into leaves and seedstalks was used in field and greenhouse inoculations. By this method it was possible to inoculate individual leaves without contaminating others, and no moist chamber incubation was necessary. The method was successful in greenhouse tests, but gave only a low percentage of infection in 1 field test. In the field many of the seedstalks inoculated in this way became infected with *Botrytis allii*.

Inoculation by injecting a spore suspension into dormant bulbs was also widely used in this study. Bulbs ranging in size from 3 to 100 grams were injected at their centers with a trace to about 1 cc of spore suspension with a hypodermic syringe. The syringe needle was inserted to about the center of the bulb, withdrawn about a millimeter and compressed, which forced a considerable amount of the spore suspension between the leaf bases. The success of this method might be considered surprising in view of the known toxicity of onion sap to the sporangia. It is likely, however, that by this manner of injection, the sporangia were forced beyond the region of injury, to the surface of normal leaf bases where infection started. By this injection method, systemically infected plants indistinguishable in growth symptoms from naturally occurring systemic infection have been produced. Occasionally only 1 or 2 of the growing points from the bulb are infected by this manner of inoculation, but such partial systemic infection also occurs under natural conditions. The inoculated bulbs grow as readily as noninoculated bulbs, and usually produce leaves large enough for sporulation in about 2 weeks under greenhouse conditions. Murphy and McKay (44) tried several methods of direct inoculation of bulbs, including inserting sporangia into the bulbs, but secured no infection by any method. The failure may have been because the sporangia remained localized near the wounded tissue.

Penetration Through Stomata.—The germ tubes of *Peronospora destructor* penetrate the onion through the stomata on leaves and seed-stalks. In my observations an appressorium was usually formed by the germ tube over the stoma, and a vesicle was usually formed in the substomatal cavity (fig. 11, *E, F*), but no appressorium is illustrated by Trelease (69), Shipley (60), Whetzel (76), or Katterfeld (31). In 1 test on December 13, 1935, 53 stomatal penetrations showed 42 with appressoria apparent. In a test on September 24, 1936, 27 stomatal penetrations were observed in an 11-hour culture at 13° C in dark, moist chambers, and of these 16 showed definite appressoria over the stomata, 4 showed no appressoria, and 7 were doubtful.

Penetration of the stomata by the germ tubes from onion-mildew sporangia causes the nuclei of the ordinary elongate onion-leaf epidermal cells to move toward the penetrated stomata. Results of one set of observations 11 hours after inoculation at 13° C in the dark were as follows:

Condition of nuclei of inoculated leaves	Number
Nonpenetrated stomata (20 observed)	
Nuclei of adjacent cells in approximately central position.....	20
Nuclei of adjacent cells showing displacement from central position.....	0
Penetrated stomata (20 observed)	
Nuclei of adjacent cells in approximately central position.....	1
Nuclei of adjacent cells showing displacement from central position.....	19
Nuclei of laterally adjacent cells showing migration toward penetrated stomata	18
Migration in 1 cell only.....	2
Migration in both cells.....	16
Nuclei of terminally adjacent cells showing migration toward penetrated stomata	6
Migration in 1 cell only.....	3
Migration in both cells.....	3

This response of the nuclei adjacent to penetrated stomata is similar to that observed by Caldwell and Stone (6) with leaf-rust of wheat.

Effect of Temperature on Infection.—The effect of temperature on infection was determined in 4 tests which are summarized in table 14. In the first 3 tests, dry dormant bulbs were inoculated hypodermically and the inoculated bulbs were incubated at the test temperatures for 48 hours, after which time they were planted in the greenhouse. Infection was determined from the symptoms of systemic infection which were apparent 3 weeks after inoculation. In the hypodermic inoculations there were only 4 bulbs for each temperature treatment in each test, and in some cases only 3 bulbs grew. Infection occurred from 1° to 28° C. In 1 test, seedling plants growing in 4-inch pots were inoculated by

spraying with a suspension of sporangia, and the plants were placed in moist chambers at the test temperature for 16 hours and then placed in the greenhouse. Infection occurred from 4° to 25° C.

Incubation Period about 6 Hours.—Incubation is here used as the development of the fungus from inoculation until it establishes nutritional relations with the host. This was followed microscopically in 1 test and culturally in several tests. In the penetration process the protoplasm of the sporangium tends to mass toward the tip of the germ tube.

TABLE 14
EFFECT OF TEMPERATURE ON INFECTION WITH ONION DOWNY MILDEW

Temperature ° C	Bulbs inoculated hypodermically			Plants inoculated by spraying with a spore suspension. 4 p.m. February 28, 1938
	2 p.m. August 17, 1936	August 25, 1937	4 p.m. September 4, 1937	
	per cent	per cent	per cent	per cent
1.....	50	...	...	0
4.....	75	100	100	100
7.....	33	...	...	100
10.....	33	100	100	100
13.....	100	100	100	100
16.....	75	100	...	100
19.....	75	50	...	100
22.....	0	...	100	100
25.....	50	...	100	9
28.....	0	...	100	0

and as growth progresses the sporangium is first emptied of its protoplasm, then the germ tube, and then the appressorium. In 1 test, an appressorium was formed in 4 hours and infection hyphae from the substomatal vesicle in 8 hours. Such observations, however, do not indicate accurately when the fungus is beyond the reach of ordinary environmental influences, which might be considered the critical end point of the incubation process.

Since high humidity is necessary for infection, and hence for successful incubation, it is a simple matter to determine how long an incubation period is necessary for infection by transferring inoculated plants from a moist incubation chamber to a dry environment after different periods. A dry environment on the leaf surface was insured by exposing the plants to an electric fan on removal from the incubation chamber. As another method of determining whether or not the fungus had established itself within the host, the onion plants were sprayed after specified incubation periods with fungicides known to be toxic to the fungus. This spray treatment should kill all the fungus germ tubes on the surface

TABLE 15

ERADICANT TREATMENTS FOR ONION DOWNY MILDEW WHEN PLANTS WERE REMOVED FROM MOIST CHAMBER AFTER SPECIFIED INCUBATION PERIODS AND DRIED OR SPRAYED TO KILL THE FUNGUS

Time of inoculation, temperature during test, and treatment on removal from moist chamber	2 hours from inoculation to treatment		3 hours from inoculation to treatment		4 hours from inoculation to treatment		5 hours from inoculation to treatment		7 hours from inoculation to treatment		12 hours from inoculation to treatment	
	Plants number	Infection per cent	Plants number	Infection per cent	Plants number	Infection per cent	Plants number	Infection per cent	Plants number	Infection per cent	Plants number	Infection per cent
7 p.m. August 14, 1936: Dried..... Sprayed with 2 per cent lime-sulfur + spreader..... Sprayed with 1 per cent bordeaux + spreader.....	9 9 9	0 0 0	.. .. ..	.. .. ..	8 10 12	0 0 0	10 11 14	10 0 0	9 10 8	11 20 0	10 9 9	80 67 55
4 p.m. September 3, 1936, at 17° to 15° C: Dried..... Sprayed with 2 per cent lime-sulfur + spreader..... Sprayed with 1 per cent bordeaux + spreader.....	.. .. .. ..	.. .. .. ..	8 10 7	0 0 0	.. .. ..	.. .. ..	10 9 12	0 0 0	12 9 9	42 67 67	14 16 15	71 12 66
5 p.m. September 23, 1936, at 18° to 13° C: Dried..... Sprayed with 2 per cent lime-sulfur + spreader..... Sprayed with 1 per cent bordeaux + spreader.....	.. .. .. ..	.. .. .. ..	.. .. .. ..	.. .. .. ..	7 7 6	71 86 100	.. .. ..	.. .. ..	7 9 11	71 78 72	7 10 6	85 90 100
9 a.m. October 14, 1936, 13° C: Dried..... Sprayed with 2 per cent lime-sulfur + spreader.....	.. .. ..	.. .. ..	14 9 9	29 0 0	9 8	100 100 100	9 12	100 100	.. .. ..	.. .. ..	.. .. ..	.. .. ..
12 m. April 15, 1937, 13° C:° Dried..... Sprayed with 2 per cent rosin lime-sulfur.....	28 30	0 0	25 24	0 0	36 25	0 0	.. ..	.. ..	30 30	23 0	28 ..	54 ..
9 a.m. June 7, 1937, 13° C:° Dried..... Sprayed with 2 per cent rosin lime-sulfur.....	22 29	0 0	.. ..	.. ..	32 38	0 0	34 30	0 0	82 98	11 24	.. ..	.. ..

* Seedling plants were used in these tests, all previous tests were with plants grown from bulbs.

of the leaf, and it was thought that such fungicides might follow the germ tubes into the stomata and kill the fungus even long after the latter was beyond the reach of the killing action of dry air. Tests of the use of these eradicant methods to determine the incubation period of the onion downy mildew, summarized in table 15, show considerable variation but indicate that the fungus is beyond the reach of injury by drying in 3 to 7 hours, and that lime-sulfur and bordeaux-mixture sprays were no more effective than drying in preventing infection in such tests.

Rate of Growth of Mildew Mycelium in Onion Leaf.—To determine the rate of growth of onion-mildew mycelium in the leaf, blocks of plain agar and potato dextrose agar bearing sporangia were applied to marked positions on onion leaves, and the inoculated plants were incubated overnight in a moist chamber. Eleven days after inoculation these plants, in a test of February 10, 1938, were incubated in a moist chamber, and the extent of sporulation above and below the point of inoculation was measured.

Of 15 leaves inoculated with single blocks of plain agar bearing sporangia, all showed luxuriant sporulation. The total length of the sporulating surface on the leaf averaged 43 mm. This sporulation averaged 17 mm above the point of inoculation with a minimum of 7 mm and a maximum of 28 mm. The length of sporulating surface below the point of inoculation averaged 26 mm with a minimum of 15 mm and a maximum of 33 mm. The length of the sporulating surface below the point of inoculation for 13 of the 15 leaves was greater than the length above, and for all 15 averaged 53 per cent greater. The extent of the mycelium in the leaf tissues beyond the limit of sporulation was not measured in this test, but in the other tests it has ranged from 15 to 22 mm and averaged 18 mm below the lower limit of sporulation. By assuming the value of 18 mm in this test, the rate of growth of mildew mycelium along a leaf would be about 3.2 mm per day, or 134μ per hour distally, and 4.0 mm per day, or 167μ per hour proximally, or a total extension of about 7.2 mm per day, or 300μ per hour in both directions. This rate of growth is about twelve times that of germ tubes from single sporangia as reported for the agar cultures.

In the test with sporangia on blocks of potato dextrose agar, 20 leaves were inoculated. Eleven days after inoculation only 8 of these showed sporulation, and the extent of the sporulating surface averaged 27 mm per leaf with a minimum of 14 and a maximum of 24 mm. The success of the inoculations and the rate of growth of the mycelium was therefore less from sporangia seeded on potato dextrose agar than from those on plain agar.

Three tests were made to determine if fungicide sprays applied to the surface of leaves 24 hours after inoculation affected the rate of growth of the mycelium in the leaf. In a test of January 5, 1938, leaves inoculated by means of plain agar blocks containing sporangia were treated with a brush below the point of inoculation with 2 per cent rosin lime-sulfur or 1 per cent bordeaux plus 0.5 per cent sulfonated miscible oil, and the extent of the mycelium after 19 days was followed by staining the cleared leaves. In this test the extent of the mycelium in 8 control leaves averaged 50 mm below the point of inoculation, in 3 leaves treated with rosin lime-sulfur 40 mm, and in 5 leaves treated with bordeaux mixture 47 mm. In a similar test of February 17, 1938, and harvested 11 days after inoculation, the extent of the mycelium in 11 control leaves averaged 46 mm below the point of inoculation, in 6 leaves treated with rosin lime-sulfur 47 mm, and in 5 leaves treated with bordeaux 47 mm. In a test of March 1, 1938, the extent of growth of the fungus was followed by measurement of the sporulating surface only (probably unreliable for such tests), and 0.2 per cent malachite green plus 0.2 per cent sodium oleyl sulfate was included in the fungicides tested. In this test the extent of the sporulation was 32 mm below the point of inoculation for 8 control leaves, 16 mm for 4 leaves treated with rosin lime-sulfur, 20 mm for 5 leaves treated with bordeaux, and 34 mm for 3 leaves treated with malachite green. According to these last 3 tests there was no certain effect of the external applications of these fungicides on the internal rate of growth of onion-mildew mycelium. According to tests to be described later (p. 667), however, these materials used as sprays did apparently increase the yield of infected plants.

Infection Period about 7 Days.—To determine the time from inoculation until the fungus is sufficiently mature to sporulate, inoculated plants were incubated in moist chambers each night after inoculation. The minimum period from the night of inoculating the plants to the night of first sporulation was 5 days (June 4, 1936), but in this case only a very few sporophores were formed. The minimum period from inoculation to luxuriant sporulation was 8 days. To determine whether or not plants were infected in most routine inoculation and fungicide tests, they were generally incubated 10 to 12 days after inoculation. At 10 days after inoculation, symptoms usually were not or were only barely evident. In many cases of young infections, sporulation had occurred on plants on which I could detect no symptoms. In the field also, luxuriant sporulation may occur on tissues showing no symptoms. This is contrary to the situation with the downy mildews of hop, cucumber, and snapdragon, with which diseases I have been able to observe symptoms before sporulation could be induced.

EPIDEMIOLOGY

The epidemiological factors I would suggest as critical in determining the incidence and severity of downy mildew on onions in California, are, in order of importance: source of inoculum, temperature, moisture conditions, and wind. It is, of course, impossible to establish an adequate factual basis for these suggestions on my limited field observations.

During 1935 to 1940, onion downy mildew had apparently not become conspicuous or abundant on onions grown for seed in the Cotati, Sacramento—San-Joaquin delta, and southern Santa Clara Valley regions until the spring months, if at all, whereas it usually appeared earlier at Milpitas, and had been found at all seasons in the truck-garden districts of San Francisco Bay region. I believe these differences between districts are due in part to relative abundance of inoculum. In the first three districts mentioned, heavy and early infection would occur only if there was considerable systemic infection in the bulbs used as planting stock, and there usually is not. The infection which usually does appear later in the season probably arises from a few systemic infections, from oöspores in soil or refuse, or from sporangia wind-borne from other districts. At a seed farm near Milpitas, one of the reasons the disease develops earlier and with greater severity than in the other seed-producing localities is probably the large number of varieties of varying degrees of susceptibility, some of which probably always carry some systemic infection. Onions are planted earlier at Milpitas than in the other districts and this might be responsible for the greater spread of the disease. Local weather conditions at Milpitas may be especially favorable to the disease. In the truck gardens of the San Francisco Bay region, where onions are grown throughout the year, principally for greens, the source of inoculum of new plantings is probably principally the sporangia produced on infected earlier plantings.

From the findings of Katterfeld (31), Cook (12), McKay (36), and from data of tables 8, 9, 12, and 14 of this paper, it appears safe to conclude that onion downy mildew is favored by relatively low temperatures, with an optimum temperature of about 13° C, and a maximum of around 25° C. In nature, however, day temperatures are much higher than night temperatures, and it may be possible for onion mildew to thrive with prevailing day temperatures well above the optimum. The relation of prevailing temperatures to the field development of the disease has not been adequately studied.

High humidity at night is necessary for sporulation, and free water is believed necessary for germination and infection, but to what extent

these are limiting to the development of onion mildew under natural conditions has not been determined. Conditions which favor the development of a high humidity on the leaf surface are still air, and clear nights, fog, or rain. Rain, however, might be injurious to the disease in washing the sporangia into the soil. From the observed severity of onion mildew in periods of little or no rain but with abundant dews, I believe rain is of little importance in the development of onion mildew in California, and this belief is supported by the heavy infection which has resulted on plants dusted with dry sporangia and incubated in moist chambers (84).

From data of the time required for sporulation, germination, and penetration, Katterfeld (31) believed that 1 humid night was sufficient for the production of, and infection with, the same sporangia. From similar data collected by myself, I believe that 2 humid nights are usually necessary—1 humid night for sporulation, 1 day period for dissemination of sporangia, and 1 night with free moisture on the leaves for germination and penetration. Conditions which may delay the drying of the plants after a heavy dew or fog are high humidity, any conditions which interfere with air currents, and rain. A rank growth of weeds may delay the drying of onion leaves and favor mildew infection. At Cotati an isolated patch of wild morning-glory, or bindweed (*Convolvulus arvensis*), in an onion field was apparently responsible for the increased severity of mildew as observed on July 16, 1940. In the area of heavy weed infestation, 99 out of 100 seedstalks showed mildew infection and only 7 out of 100 were erect and appeared as if they might mature some seed; in the field beyond the margin of the wild morning-glory, 92 out of 100 seedstalks were infected and 21 out of 100 appeared as if they might mature seed.

Wind is considered important in reducing the severity of onion mildew in the Sacramento—San—Joaquin delta region. In the eastern portion of the Delta, a dry north wind may blow for several days at a time, and certain growers believe this wind is effective in checking the disease after it has become established. In the western portion, strong westerly winds may prevail for periods of several days, but no effect of these winds on onion mildew has been suggested. Near Milpitas, winds are less, and onion mildew is more severe than in the Delta region. Wind is also of importance in determining the extent and direction of spread of the disease by means of air-borne sporangia.

Shipley (60) and Walker (75) have reported that in the Bermuda and the Canary Islands, respectively, mildew was apparently less severe on the southern coasts than on other parts of the islands, and they attribute this to the wind and southern exposure.

CONTROL BY EXCLUSION AND ERADICATION

In Finland (19) laws designed to exclude the disease from the country have been passed, but no information on the success of such a control method is available.

Hot-water treatment of the seed to destroy seed-borne infection has been suggested by McWhorter (37) and tested by Newhall (49), but since there is no good evidence of seed transmission there is naturally no evidence of control by seed treatment, though Muncie (42) reported that formaldehyde treatment of onion seed reduced mildew carried on the seed.

Murphy and McKay (44, 46) have demonstrated the effectiveness of heat in destroying onion mildew in infected bulbs. In their first report (44), 8 hours at 40° C was sufficient to kill out such bulb-borne infections but in their later tests (46) 8 hours at 40° C was inadequate. Using bulbs averaging about 20 grams in size and artificially inoculated 9 days before heat treatment on September 13, I attempted to determine the effect of short exposures of the bulbs to 41° C dry heat on the later development of onion mildew. Of 15 control bulbs, 11 grew and 10 showed systemic infection on October 16. Of 14 bulbs exposed to 41° C for 4 hours, 12 grew and none showed systemic infection. Of 14 bulbs exposed at 41° C for 32 hours, 11 grew and none showed systemic infection. Treatments for 8 and 16 hours also showed complete eradication with the dry heat. According to these results, the bulbs were not injured by an exposure to 41° C for a period eight times as long as necessary to destroy the infection, which indicates that the treatment has a wide margin of safety.

Infection in growing plants was also destroyed by dry heat without injuring the plants, but here the margin of safety was narrower than with bulbs. Results of all tests are summarized in table 16. According to these results, an exposure of 4 to 6 hours in the dark at 43° C destroyed the mycelium in systemically infected plants, without killing the plants, and 8 to 10 hours at 37° C destroyed the mycelium in locally infected plants. Plants exposed to 37° C for more than 10 hours were severely injured. Onion foliage is therefore more easily injured by heat than are onion bulbs, and these foliage treatments are probably of no value except for experimental purposes.

Newhall (48) has indicated that destruction of top-set onions in small gardens was responsible for the light attack of onion mildew in Marion Township, New York, in 1937.

The destruction of crop refuse and the rotation of land for onion culture are widely recommended for the control of onion mildew, but little information on the value of these procedures is available.

TABLE 16
ERADICATION OF ONION MILDEW BY EXPOSING INFECTED GROWING PLANTS TO HIGH TEMPERATURE, 1938

Type of infection, date of inoculation, incubation period, and temperature of heat treatment	0 hours' exposure (control)		4 hours' exposure		6 hours' exposure		8 hours' exposure		10 hours' exposure		12 hours' exposure	
	Plants number	Infection per cent	Plants number	Infection per cent	Plants number	Infection per cent	Plants number	Infection per cent	Plants number	Infection per cent	Plants number	Infection per cent
Systemic infection, June 4, 57 days after inoculation:												
37° C.....	4	100	..	..	5	80	4	75	..	..	..	..
43° C.....	..	..	4	0	..	..	..	..	..	..	..	..
Systematic infection, July 2, 28 days after inoculation:												
37° C.....	6	67	4	100	..	..	..	..	4	25	..	..
43° C.....	..	..	..	..	6	0	..	..	..	..	..	..
Systematic infection, July 8, 23 days after inoculation:												
37° C.....	16	94	..	..	5	100	..	..	9	45	..	..
43° C.....	..	..	9	11	6	0	..	..	..	..	..	..
Local infection, June 13, 2 days after inoculation:												
37° C.....	96	94	118	13	40	2	49	0	95*	0	61†	0
Local infection, August 8, 3 days after inoculation:												
37° C.....	38	92	..	..	44	91	..	..	57	0	..	..

* Slight injury to onion plants.

† Moderate injury to onion plants. Severe injury resulted on onions exposed for 24 hours at 37° C.

CONTROL WITH FUNGICIDES

Shipley (60) was one of the first to consider the means of control of onion mildew. The foliage treatments which he considered most promising as protective measures were dusting with a mixture of freshly burned quicklime and sulfur, and spraying with 0.1 per cent ferric sulfate. There is no record that he actually used these mixtures. In 1897, Jones (30) applied standard bordeaux mixture, standard bordeaux plus soap, potassium sulfide, and sulfur dust to onions for mildew control. No mildew appeared, the solutions did not adhere well, and the bordeaux was injurious to the leaves. Whetzel (76) reported the use of bordeaux mixture for onion-mildew control in New York but no evidence was presented to indicate that it was effective. Ralph E. Smith (61) reported that spraying experiments for the control of onion mildew in southern California were arranged in 1908, but the season was not a favorable one for the disease, and the results were not satisfactory. Hearst (24) reported tests of the use of bordeaux with and without stickers, applied once a week and oftener before mildew appeared on the leaves. In 1917, the only year for which results are given, "the whole patch was blighted evenly over treated and untreated rows." Edgerton (18) reported trials of up to 11 applications of bordeaux, bordeaux plus distillate, and bordeaux plus nicotine for the control of downy mildew, a white-spot disease, and *Macrosporium* on onion. No data on disease incidence are given but he states that the treatments did not show a significant increase in yield. Katterfeld (31) made 7 applications of 1.0 to 1.5 per cent bordeaux in 2 months to one onion plot and left one plot as a control. His results indicated that the bordeaux application decreased the percentage of systemically infected bulbs by 60 per cent, increased the average weight per infected bulb by 39 per cent, and increased the average weight per healthy bulb by 9 per cent. No data on the gross or relative total yield of the two plots are presented. Milbrath (41) reported that among the substances tested for onion downy mildew were lime-sulfur, sulfur dust, copper-lime dust, commercial colloidal copper, copper stearate, bordeaux mixture plus stickers, and light summer oils. Of these substances, copper-lime dust and bordeaux mixture plus paper hanger's paste gave most promise in adhesiveness and fungicidal value. Doran and Bourne (15) applied bordeaux mixture and copper-lime dust for the control of onion mildew. They report that copper-lime dust injured the plants in 2 out of 3 seasons and that bordeaux mixture caused a slight increase in yield in the absence of both diseases. Investigators in Wales (23, p. 277) reported that a "resin-sulfur spray mixture" was superior to all other chemicals tested for spreading properties

on onions, and gave fairly satisfactory results in onion-mildew control, but no details of these experiments are given. Cook (12) reported that spraying with bordeaux mixture and dusting with copper-lime dust and sulfur dust failed to give any indication of control of onion mildew. McWhorter and Pryor (38) believed that copper sprays of the bordeaux group were neither sufficiently toxic nor selectively toxic to onion mildew to ensure any practical control of onion mildew, even where generous applications were made with efficient stickers and spreaders. They reported inadequate coverage and injury to onions from lime-sulfur. They found malachite green highly toxic to the onion-mildew fungus and suggested the use of a mixture of malachite green and cuprous oxide as a control agent for downy mildews. Newhall (49) reported that malachite green completely inhibited germination of the sporangia of onion mildew at dilutions up to 1 to 150,000, while copper sulfate permitted germination at dilutions greater than 1 to 75,000. In 1939, Newhall (50) stated that 4 weekly applications of "potash-rosin-lime-sulfur, red copper oxide, and malachite green with a number of wetting agents such as Grasselli spreader, Ultrawet, Santomerse, cottonseed-oil emulsion, and Lethane" failed to hold onion mildew in check. Investigators in New South Wales (51) reported that spraying with bordeaux mixture plus fish oil gave good results in the control of onion mildew. These reports of investigations of fungicidal control are so fragmentary, contradictory, and so poorly supported by data, that a reader might appear safe in concluding that fungicidal control of onion downy mildew has never been adequately demonstrated.

In addition to the specific reports of attempts at the fungicidal control of onion mildew, which have been briefly reviewed, many recommendations and generalizations concerning the control of onion mildew have appeared in the literature, but in most cases the basis for these recommendations is not given, and in view of the published experimental evidence the recommendations appear unjustified. For instance, Osmun (52) states: "Control methods for onion blight have been worked out." He recommends the destruction of onion refuse, the rotation of onion land, providing conditions favorable to the aeration of the plants, and spraying with 4-4-50 bordeaux mixture. McCallum (35) recommends spraying every 10 days with bordeaux mixture plus resin sticker. Sutton and Sons (64) state: "In its early stages the mildew may be successfully dealt with by freely dusting the plants with flowers of sulfur when wet with dew, or by the application of sulphide of potassium in the proportion of one ounce to a gallon of water." Several growers in California have expressed the opinion that onion mildew can be partially controlled by applications of sulfur dust, but no supporting evidence is available.

Concerning soil treatments for onion mildew there is little information. Shipley (60) cautioned against the use of wood ashes on onions because the potash might favor onion mildew, but certain manufacturers* have made claims in farm papers that potassium sulfate controlled onion mildew.

Tests of fungicides for the control of onion mildew started with a field test in 1935, but as greenhouse tests formed a basis for continued efforts in field tests, the laboratory and greenhouse trials will be reported first. Previous reports of this work have been published (78, 80, 82, 83).

Toxicity of Spray Fungicides to Sporangia of Onion Mildew.—I have considered that *in vitro* studies of the toxicity of chemicals are not of great importance in testing materials for their protective value for onion downy mildew. While toxicity to the fungus may be a primary prerequisite for any material to be considered as a fungicide, other factors such as host coverage and the effect of the host on the fungicide may be of great secondary importance. And since the final resultant of these three factors is evaluated in a protective test with little more effort than a toxicity test, I have preferred the protective tests, even though the latter are less adaptable to standardization in procedure and evaluation of results. Some basis for these opinions is given in the toxicity data which follow.

The importance of substrate in toxicity studies is well illustrated in the action of sulfur on onion-mildew sporangia. Sporangia in water suspension were added to glass, agar, and leaf surfaces that had been dusted with sulfur, and adequate controls were maintained. After about 24 hours, germination of the sporangia was counted—100 sporangia counted for each treatment in each test—and the results of these tests were as follows:

Substrate on which sporangia in suspension were placed	Number of tests	Average germination, in per cent
Slide	7	85
Slide + sulfur	7	74
1 per cent plain agar	7	78
1 per cent plain agar + sulfur	7	0.14
Normal detached leaves	1	80
Normal detached leaves + sulfur	1	60
Rubbed detached leaves	1	80
Rubbed detached leaves + sulfur	1	2

On glass slides and on normal detached leaves, dusting sulfur (Flotox) had practically no effect on the germination of sporangia, but on plain agar and on leaves that had been rubbed so that water would adhere

* An advertisement in Pacific Rural Press 132:266. 1936.

better, sulfur dust was highly toxic to the sporangia. On sulfur-dusted agar plates to which sporangia had been added, hydrogen sulfide was present in large amounts as indicated by the darkening of lead acetate paper but no hydrogen sulfide was detected from the plain agar without sulfur or from sulfur-dusted slides to which a spore suspension had been added. The effect of rubbing the leaves was presumably to allow a more intimate contact between leaf, sulfur, water, and sporangia.

TABLE 17

EFFECT OF SUCROSE, PEPTONE, AND ASPARAGINE ON THE TOXICITY OF BORDEAUX MIXTURE AND ROSIN LIME-SULFUR TO ONION-MILDEW SPORANGIA

Fungicide suspension	Test-antagonizing substance added to fungicide suspension			
	Germination* in water, control	Germination* in 1 per cent sucrose	Germination* in 1 per cent peptone	Germination* in 1 per cent asparagine
Control, water.....	per cent 75	per cent 82	per cent 87	per cent 85
Bordeaux:†				
0.3 per cent.....	..	..	..	0
0.1 per cent.....	..	..	0	65
0.03 per cent.....	..	..	62	74
0.01 per cent.....	0	0	66	.
0.001 per cent.....	17	12	..	.
0.0001 per cent.....	81	68	..	.
Rosin lime-sulfur:‡				
0.1 per cent.....	0.2	0.0	0.2	0.0
0.01 per cent.....	44	29	38	42
0.0001 per cent.....	57	51	53	43

* 100 sporangia were counted in each test and each value is the average of 2 to 6 tests (mostly 4 to 6) on different days.

† Percentage is given as per cent by weight of each constituent. This mixture therefore contained 0.3 per cent $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ (0.077 per cent copper) and 0.3 per cent $\text{Ca}(\text{OH})_2$.

‡ Percentage given is per cent by weight of rosin, which was used as rosin soap containing 25 per cent rosin. The lime-sulfur was present in the ratio of 1 volume of lime-sulfur to 1 volume of rosin soap. This mixture therefore contained 0.04 per cent rosin soap and 0.04 per cent liquid lime-sulfur.

Antagonism of Peptone and Asparagine for Copper.—The work of Kunkel (33) on the antagonism of peptone to nitrates has emphasized the possible role of antagonism in toxicity tests. The effect of sucrose, peptone, and asparagine on the toxicity of bordeaux mixture and rosin lime-sulfur was measured in 6 tests, which are averaged in table 17. In these tests 3 cc of water or of the test antagonizing agent—sucrose, peptone, or asparagine—at a concentration four times that indicated in table 17 was added to appropriate vials; 3 cc of bordeaux mixture or rosin lime-sulfur at four times the concentration indicated in the table was then added to the appropriate vials. To each vial 6 cc of a spore suspension of *Peronospora destructor* was added, and the vials agitated about every 5 minutes for an hour. Each vial of spore suspension plus test chemicals

was poured onto a separate plate of cold plain agar, allowed to settle about a minute, and the superfluous liquid poured off. After the plates were exposed to dry somewhat for a few minutes they were closed and incubated at 13° C, and the percentage germination of 100 spores on each plate was determined after about 24 hours. The results presented in table 17 show that the critical concentration (highest concentration tested which allowed germination) of bordeaux was increased from 0.01 per cent without any antagonizing agent to 0.1 per cent with 1 per cent peptone, and 0.3 per cent with 1 per cent asparagine. Sucrose had no apparent effect on the toxicity of bordeaux, while none of the materials tested apparently affected the toxicity of rosin lime-sulfur. These tests were not followed with adequate tests of the role of antagonism on onion leaves.

Greenhouse Methods of Testing Protective Fungicides.—All greenhouse tests of fungicides were performed with plants grown in 4-inch pots. In the early tests, plants were grown from bulbs of an unknown but highly susceptible variety secured in the market. In most of the fungicide tests, seedlings of Australian Brown with 10 to 60 plants per pot were used as test plants, and the inoculum was grown on large plants grown from bulbs. Even though field control was primarily a problem of protecting the seedstalks, all the greenhouse tests were on onion foliage. Plants were sprayed with an atomizer using 35 pounds air pressure, or dusted with a hand duster. Dilute sprays, concentrated sprays (or vapor-dust sprays, also called fogs), or dry dusts were used.

With the ordinary dilute sprays the plants were held at about 10 inches from the atomizer and sprayed till runoff occurred. This gave a conveniently observed end point. With vapor-dust sprays or with dry dusts, standardized application was more difficult, for protection from these vapor-dust sprays could be secured from deposits which could be seen only with difficulty. Most of the dosages of vapor-dust sprays were governed by timing, and an exposure of plants for 4 seconds to vapor dust at about 2 feet from the nozzle gave a satisfactory protective coating with several sprays. In most of the tests, some of the sprayed plants were subjected to a weathering test soon after the spray had dried on the leaves. In some tests previously reported (80), sprayed plants on which the fungicide had dried were subjected to weathering from natural rain, and its effect on protection was determined. Rain was very unreliable in occurrence, however, and in most later tests the sprayed plants were subjected to artificial weathering by spraying them with water. This was not compared with natural weathering in its effect on protection in the same test, but artificial weathering caused a marked reduction in the protective action of several sprays and is believed to be fairly

comparable to rain. After an arbitrary weathering period the plants were dried, and later inoculated by spraying them with a suspension of sporangia of *Peronospora destructor*, and the inoculated plants were incubated overnight in a moist chamber. The following morning the plants were placed on a greenhouse bench where the prevailing temperatures usually varied from around 20° C during the day to 15° C at night. Ten to 12 days after inoculation the plants were incubated overnight in moist chambers to induce sporulation, and infection was recorded as the percentage of inoculated leaves sporulating for plants from bulbs, or percentage of plants sporulating for plants from seed. In each test 1 or 2 pots of plants not treated with a fungicide were maintained as controls, and if these did not show over 30 per cent infection the results of the test were not used. Infection failures occurred occasionally during the summer months.

Fungicides Used in Spraying Tests.—Bordeaux mixture was prepared by adding 10 per cent stock solutions of copper sulfate and quicklime in equal proportions to the required amount of water, and the concentration is expressed as percentage by weight of copper sulfate. Rosin soap was prepared from the following :

Ingredient	Parts by weight
Water	68
Potassium hydroxide	5
E-grade lump rosin	25
Alcohol	2

In earlier preparations the alcohol was omitted. Later the water, potassium hydroxide, and rosin were heated together to form a soft soap, and the alcohol was added. Commercial liquid lime-sulfur with a specific gravity of 1.26 was used. Rosin lime-sulfur was prepared by adding first the required amount of rosin soap and then the same volume of lime-sulfur to the water, and the concentration is expressed as the percentage by volume of each ingredient. The cottonseed oil and other vegetable and animal-oil emulsions were prepared by emulsifying 1 pint of oil with 1 egg in a mayonnaise mixer. The self-emulsifying cottonseed oil contained approximately 85 per cent cottonseed oil and 15 per cent phthalic glyceryl alkyd resin. Most of the other fungicides tested were proprietary products.

Relation of Leaf Growth to Fungicidal Protection.—Onion leaves and seedstalks elongate principally at the base, and the younger leaves may grow very rapidly. This growth from the base makes protection with fungicides more difficult because infection on the newly exposed tissues may girdle the leaf or stalk at that point and eventually kill all tissues

beyond, whether or not they are covered with a protective fungicide. No tests were made to determine if infection actually takes place on the newly exposed tissues at the base of the leaf or seedstalk, but such is to be expected, and seems to be the most natural explanation of the results of table 18.

The rate of growth of onion leaves was ascertained by successive measurements of the same leaves in 3 tests. In one of these (table 18) all the leaves of one plant grown from a bulb were marked with ink at the

TABLE 18
REGION OF GROWTH OF ONION LEAVES, GREENHOUSE, DECEMBER 3-10, 1936

Leaf group and region of growth	Increase in length of leaves, per leaf					
	After 2 days		After 5 days		After 7 days	
	Average	Maximum	Average	Maximum	Average	Maximum
	mm	mm	mm	mm	mm	mm
Leaves which showed growth below point of emergence (7 leaves):						
Below point of emergence	16	22	44	62	64	90
Above point of emergence	6	11	11	22	16	25
Leaves which showed no growth below point of emergence (3 leaves):						
Above point of emergence	3	10	5	15	7	20
Average (10 leaves):						
Below point of emergence	11	..	31	..	45	..
Above point of emergence	5	..	10	..	12	..

point where they emerged from or were attached to the leaf sheath, and the total length of each leaf was carefully measured. Measurements made 2, 5, and 7 days later showed that the 3 outer leaves made no growth below but averaged 7 mm above the initial mark. Seven leaves showed four times as much growth below as above the point of emergence.

In 2 other tests the rate of leaf growth and its apparent effect on fungicidal protection were followed simultaneously. On each of several days, 2 plants grown from bulbs were sprayed with 1 per cent bordeaux plus 0.5 per cent sulfonated miscible oil. This was an effective protective spray which left a conspicuous deposit. As the sprayed leaves grew, unsprayed leaf tissue was exposed below the point at which the leaves emerged from the leaf sheath at time of spraying, and was easily distinguished by the absence of spray deposit. All sprayed plants and 2 control plants were inoculated simultaneously after measuring the leaf growth of the sprayed plants. The results on leaf growth and infection are given in table 19. The values for leaf growth are extremely variable because each

value represents one set of measurements on a different set of 2 plants from each other value, but leaves of individual plants grew as much as 5 cm in 2 days. Infection of sprayed leaves increased with the amount of leaf growth, but in the test of April 10 there was no apparent increase in infection from 3 to 15 days. This is probably because only some of the younger leaves showed any considerable growth and the older leaves had already reached their maximum growth. The 2 tests of table 19 were

TABLE 19
RELATION OF LEAF GROWTH TO THE ACTION OF A PROTECTIVE FUNGICIDE*
FOR ONION DOWNY MILDEW, 1936

Date of test and period from spraying to inoculation	Total leaves	Leaves showing growth	Average growth of leaves showing growth	Maximum growth of leaves	Leaves infected
	number	number	mm	mm	per cent
April 10:					
0 days.....	22	..	..	..	0
3 days.....	7	..	..	6	43
5 days.....	17	..	..	50	41
7 days.....	15	..	..	55	60
9 days.....	15	..	..	87	47
11 days.....	9	..	..	80	44
12 days.....	8	..	..	67	50
15 days.....	13	..	..	142	54
Not sprayed.....	11	..	..	..	100
May 3:					
0 days.....	11	..	..	..	0
1 day.....	11	4	11	12	0
2 days.....	16	9	25	50	6
3 days.....	12	7	35	50	8
6 days.....	10	6	102	150	40
Not sprayed.....	9	..	..	..	89

* Combined spray of 1 per cent bordeaux + 0.5 per cent sulfonated miscible oil spreader. There was no control on the inherent deterioration with time of the bordeaux in this test, but other tests have indicated that deterioration of the bordeaux could not be responsible for these results.

performed before the tests of table 18, and in the tests of table 19 I did not know or take into account the fact that a small amount of growth may occur above the point of emergence of the leaves from the leaf sheath.

Wetting Agents for Onion Leaves.—Onion leaves are not readily wetted by ordinary solutions or water suspensions, and this difficulty of wetting increases the difficulty of depositing a protective covering on the leaves. To compare the wetting capacity of onion leaves with that of other foliage, the tests summarized in table 20 were performed. The weighed test leaves were held in a vertical position and sprayed with water from a compressed-air atomizer held at a distance of about 16 inches, with a resultant spray of very low impact pressure. Spraying was continued until runoff had just started, and presumably the peak

of deposit had been reached and just passed. The percentage leaf area covered with water was estimated and the leaf again weighed to determine the initial deposit. The leaf was then shaken twice to remove all but the tightly adhering water, the area covered with water was again estimated, the leaf again weighed, and its area measured. Four determinations were made for onion and two for each surface of the other leaves.

TABLE 20
COMPARATIVE DEPOSIT OF WATER SPRAY ON THE LEAVES OF VARIOUS PLANTS,
MARCH 21, 1941

Kind of leaf and leaf surface	Estimated leaf area covered with water		Measured deposit of water per square decimeter of leaf surface	
	Before shaking	After shaking	Before shaking	After shaking
	<i>per cent</i>	<i>per cent</i>	<i>grams</i>	<i>grams</i>
Onion (4 determinations).....	5	2	0.44	0.07
Pinto bean, primary:				
Lower (2 determinations).....	55	50	1.32	0.53
Upper (2 determinations).....	70	62	1.59	0.47
No. 45 cantaloupe:				
Lower (2 determinations).....	45	7	3.35	0.88
Upper (2 determinations).....	30	2	2.02	0.29
Gravenstein apple:				
Lower (2 determinations).....	55	10	3.76	1.13
Upper (2 determinations).....	35	10	2.24	0.38
Potato:				
Lower (2 determinations).....	85	85	1.47	0.64
Upper (2 determinations).....	50	35	0.96	0.36
Tobacco (<i>Nicotiana glutinosa</i>):				
Lower (2 determinations).....	50	12	1.76	0.57
Upper (2 determinations).....	60	50	1.41	0.54

With onion almost any type of handling or rubbing greatly increases the wettability of the leaves, and consequently care was taken that the leaves were handled as little as possible before spraying. High impact pressures also greatly increase the wetting capacity of water on onions, and leaves held in a vertical position retain less water than leaves in a horizontal position. These tests were therefore performed under conditions favoring a low deposit on onions, but the tests on the other foliage were performed under similar conditions and on the same day. According to table 20, when the spray is not reduced by shaking and when onion leaves are compared with the average of upper and lower leaf surfaces of other plants, onion leaves will retain only about 30 per cent as much as bean leaves, 16 per cent as much as cantaloupe, 15 per cent as much as apple, about 36 per cent as much as potato, and 28 per cent as much as

tobacco. After shaking, the relative deposit on onions was even less. However, the estimated percentage of the leaf area covered with water, though subject to greater error, is probably more useful than the measured deposit in comparing the different types of foliage. The estimated fractional area covered by water on onion was less than 10 per cent of that on the other foliage, before and after shaking. The apparent discrepancy between estimated percentage leaf area covered and measured

TABLE 21
GREENHOUSE TESTS OF SPRAY SUPPLEMENTS AS PROTECTIVE FUNGICIDES
FOR ONION DOWNY MILDEW

Spray material	Coverage	Not weathered		Weathered	
		Tests	Infection	Tests	Infection
		number	per cent	number	per cent
Control not sprayed		50	87	26	87
0.2 per cent sulfonated miscible oil	Fair	2	59	2	87
0.5 per cent cottonseed-oil emulsion	Fair	4	46	3	94
2.0 per cent cottonseed-oil emulsion	Fair	4	44	4	77
0.5 per cent corn-oil emulsion	Fair	1	76	1	93
0.5 per cent palm-oil emulsion	Fair	1	6	1	63
0.5 per cent coconut-oil emulsion	Fair	1	85	1	33
0.5 per cent castor-oil emulsion	Fair	1	80	1	33
1.0 per cent tank-mix spray oil No. 1	Fair	1	24	1	64
2.0 per cent miscible oil No. 1	Fair	2	38	2	74
1.0 per cent rosin soap	Excellent	4	16	0	—
4.0 per cent rosin soap	Excellent	10	9	3	56
0.2 per cent rosin fish-oil soap	Excellent	1	4	1	78
0.2 per cent sodium oleyl sulfate	Excellent	1	3	1	94
0.1 per cent sodium oleyl sulfate + resin sticker	Excellent	8	16	7	69
0.1 per cent sodium monosulfonate of butylphenylphenol	Excellent	2	0	1	91
0.2 per cent sodium monosulfonate of monobutyl diphenyl	Excellent	2	0	2	52
0.2 per cent ester of a sulfonated bicarboxylic acid	Excellent	1	0	1	100
0.2 per cent sodium salt of an alkyl naphthalene sulfonic acid	Excellent	1	0	1	68

deposit is due to the type of water coverage on the different foliage types. On onion and cantaloupe, the retained water was mainly in the forms of spherical drops, whereas on the other foliage the drops tended to spread out and adhere closely to the leaf surface. Potato was outstanding as a foliage readily wetted with water under these conditions. It is also outstanding as a crop with which spraying has been very successful for the control of a downy mildew, *Phytophthora infestans* (Mont.) D. By.

Onion leaves and seedstalks are readily wetted when certain supplements are added to water or fungicide mixtures used as sprays. Wetting agents added to a fungicide may reduce the maximum deposit on the

leaves to a value much lower than that without the spray supplement, and yet may increase the protective value of the spray (80). In addition to improving the coverage of conventional protective fungicide sprays, these supplements in themselves may exert a protective action against onion mildew. Data on the relative coverage and protective action of several spray supplements are given in table 21. Most of the materials tested showed a protective action against onion mildew on unweathered leaves, and this protection was more pronounced with the efficient wetting agents than with the oil emulsions. This protective action may have been due to the direct toxic effect of the supplement on the mildew sporangia, to the action of the supplement in reducing water deposit, or to both. Sporangia of onion mildew failed to germinate in 0.1 per cent sodium oleyl sulfate, but the toxicity of the other materials was not tested. In field tests, plants that had been sprayed with rosin soap and were later subjected to heavy dews at night, dried off in the morning as much as 3 hours earlier than unsprayed control leaves of plants. In greenhouse tests, leaves of plants sprayed with some of the wetting agents were sometimes dry when the inoculated plants were removed from the moist chambers the morning after inoculation, while the unsprayed inoculated controls were still covered with a fine mist of water such as that applied with the inoculum the previous evening. The effect on the infection process of the action of some spray supplements in preventing dew or water spray from adhering to leaves as fine drops was not studied, but it is believed it might be important.

With the exception of coconut-oil and castor-oil emulsions, with which sprays the results are probably atypical, the protective action of all spray supplements was greatly reduced by artificial weathering. On this basis their protective action is clearly distinguished from their action when combined with a conventional protective fungicide (see table 22).

Greenhouse Tests of Protective Fungicides.—Several copper and sulfur fungicides were combined with several spray supplements at various concentrations in several tests. Most combinations were apparently compatible. Malachite green formed a gummy precipitate with several supplements, but the mixture formed when malachite green and sodium oleyl sulfate were mixed dilute was the least objectionable. The addition of sodium oleyl sulfate + resin as a spreader to red cuprous oxide caused the cuprous oxide particles to stick together in groups. Results with most of the spray combinations tested are summarized in tables 22 and 23. Bordeaux mixture without supplements spread much better than water but still gave unsatisfactory coverage or protection. The most effective supplements for bordeaux were several vegetable oils

TABLE 22
COMPARISON OF SUPPLEMENTS FOR COPPER SPRAYS AS PROTECTIVE FUNGICIDES
FOR ONION DOWNY MILDEW IN GREENHOUSE TESTS

Copper fungicide and supplement	Not weathered		Weathered	
	Tests	Infection	Tests	Infection
	number	per cent	number	per cent
1.0 per cent bordeaux:				
None.....	5	76	0	—
0.2 per cent sulfonated miscible oil.....	8	4	0	—
0.5 per cent bordeaux:				
None.....	4	77	4	83
0.2 per cent sulfonated miscible oil.....	2	12	0	—
0.1 per cent sodium oleyl sulfate.....	7	5	7	9
0.5 per cent cottonseed-oil emulsion.....	9	0.3	9	0.3
0.5 per cent corn-oil emulsion.....	1	0	1	0
0.5 per cent palm oil emulsion.....	1	0	1	0
0.5 per cent coconut-oil emulsion.....	1	5	1	0
0.5 per cent castor-oil emulsion.....	1	0	1	0
0.5 per cent sardine-oil emulsion.....	1	0	1	0
1.0 per cent miscible oil No. 1.....	4	22	4	46
1.0 per cent tank-mix spray oil No. 2.....	2	44	2	29
1.0 per cent tank-mix spray oil No. 3.....	1	40	1	24
0.25 per cent bordeaux:				
None.....	2	100	0	—
0.25 per cent sulfonated miscible oil.....	10	14	0	—
0.25 per cent cottonseed-oil emulsion.....	3	4	3	6
0.25 per cent sardine-oil emulsion.....	3	0	3	0.5
0.5 per cent red cuprous oxide:				
None.....	1	48	1	73
0.1 per cent sodium oleyl sulfate.....	3	42	3	39
0.5 per cent cottonseed-oil emulsion.....	3	0	2	0
0.5 per cent castor-oil emulsion.....	1	0	1	17
0.5 per cent copper zeolite:				
None.....	4	65	4	83
0.1 per cent sodium oleyl sulfate.....	5	25	5	65
0.5 per cent cottonseed-oil emulsion.....	2	0	2	4
1.0 per cent miscible oil No. 1.....	2	29	2	87
0.2 per cent copper phosphate:				
None.....	1	98	1	92
0.1 per cent sodium oleyl sulfate.....	1	98	1	100
0.2 per cent cottonseed-oil emulsion.....	1	11	1	78
0.2 per cent copper sulfate:				
4.0 per cent rosin soap.....	4	9	0	—

and sardine oil, though bordeaux with these oils did not show as uniform a coverage as with sulfonated miscible oil or with sodium oleyl sulfate + resin. These same oils appeared to have a similar supplementary value when added to the insoluble coppers, red copper oxide, copper zeolite, and copper phosphate. In most tests the copper sprays (table 22) showed little loss in protective value after weathering, in contrast

with the protective action of some supplements used alone. Three mineral oils added to bordeaux exerted only a slight effect on its protective properties.

This general increased effectiveness of copper by the addition of vegetable oils has also been demonstrated in several tests, not reported here,

TABLE 23

LIME-SULFUR AND MISCELLANEOUS SPRAY MATERIALS AS PROTECTIVE FUNGICIDES
FOR ONION DOWNY MILDEW IN GREENHOUSE TESTS

Principal ingredient	Supplement	Not weathered		Weathered	
		Tests	Infection	Tests	Infection
		number	per cent	number	per cent
2.0 per cent lime-sulfur.	None	8	22	4	82
0.4 per cent lime-sulfur.	0.1 per cent sodium oleyl sulfate	3	35	..	..
2.0 per cent lime-sulfur	0.1 per cent sodium oleyl sulfate	18	23	5	56
0.1 per cent lime-sulfur.	0.2 per cent rosin soap	1	7	..	..
0.4 per cent lime-sulfur ..	1.0 per cent rosin soap	2	15	..	..
1.0 per cent lime-sulfur.	0.5 per cent rosin soap	2	0	..	..
1.0 per cent lime-sulfur	1.0 per cent rosin soap	9	0	..	..
2.0 per cent lime-sulfur.	2.0 per cent rosin soap	10	0	8	9
2.0 per cent lime-sulfur ..	0.5 per cent cottonseed oil	2	6	2	25
2.0 per cent lime-sulfur.	1.0 per cent miscible oil No. 1 ..	1	2	1	5
1.0 per cent rosin soap.	1.0 per cent cottonseed oil	3	40	..	..
1.0 per cent rosin soap...	2.0 per cent cottonseed oil.....	2	0	..	..
1.0 per cent wettable sulfur.	0.5 per cent cottonseed oil.....	4	12	3	40
0.2 per cent tetramethyl thiuram disulfide	None	2	0	2	57
0.5 per cent tetramethyl thiuram disulfide	None	2	0	2	4
0.1 per cent tetramethyl thiuram disulfide	0.1 per cent sodium oleyl sulfate	1	2	1	40
0.2 per cent malachite green	None	3	2	3	84
0.3 per cent malachite green.....	0.1 per cent sodium oleyl sulfate	2	1	2	2
0.2 per cent malachite green.....	0.1 per cent ester of a sulfonated bicarboxylic acid.....	1	0	..	..

of protective fungicides for bean rust, bean powdery mildew, cucumber powdery mildew, and cucumber downy mildew. In these tests, however, one proprietary mineral oil has shown supplementary properties similar to that of the vegetable oils, but this material was not tested with onion mildew.

In the hopes of obtaining more efficient methods of application than by conventional spraying, dusts and concentrated spray mixtures were tested. In one test with red copper oxide dust, 100 per cent infection occurred on the treated plants, and in 2 trials of sulfur dust 94 per cent infection occurred on the treated plants. These results indicated that

dust applications had little promise. The vapor-dust mixtures tested were 5 per cent rosin lime-sulfur; 10 per cent rosin lime-sulfur; 2.5 per cent bordeaux; 2.5 per cent bordeaux + 2.5 per cent cottonseed oil; and 5.0 per cent basic copper sulfate + 5.0 per cent cottonseed-oil emulsion. With the exception of bordeaux without supplement, these concentrated mixtures applied as vapor dusts, showed marked protective properties, before and after weathering.

Effect of Fungicides on Sporulation.—A number of fungicides have the property of inhibiting the sporulation of onion mildew without causing any marked injury to the host. Infected leaves were sprayed and allowed to dry before the plants were incubated overnight in moist chambers. Materials tested as vapors were placed in a 350 cc sealed moist chamber with infected detached leaves. The relative sporulation was rated on an arbitrary scale the following morning.

Some of the dried spray coatings which inhibited sporulation are as follows, in their apparent order of decreasing effectiveness: 2 per cent rosin lime-sulfur, 1 per cent potassium sulfide, 2 per cent lime-sulfur, 0.1 per cent sodium oleyl sulfate, 1 per cent ester of a sulfonated bicarboxylic acid, 2 per cent of a miscible pine oil containing 20 per cent copper resinate, and 0.1 per cent malachite green. Bordeaux mixture, with and without spreaders, rosin soap, and sulfur dust were relatively ineffective, though sulfur dust has been found rather effective in inhibiting sporulation of hop downy mildew (80), and Doran (14) found that sulfur dust inhibited sporulation of downy mildew in cucumber. In 2 tests rosin lime-sulfur was allowed to remain on mildewed leaves in a wet condition for 1 hour, and then washed off. In these tests the inhibition of sporulation on the night after washing and for 2 nights later was apparent, but not so marked as when the spray was allowed to dry on the leaves. Rosin lime-sulfur was more effective than lime-sulfur alone in inhibiting sporulation. But tests in which rosin soap and lime-sulfur were mixed in various proportions indicated that the effect of the rosin soap was mainly to increase the deposit of lime-sulfur, though rosin soap alone inhibited sporulation slightly.

Among the vapor materials that inhibited sporulation were those from dilute lime-sulfur, benzene, paradichlorobenzene, pine oil, and formaldehyde. Lime-sulfur at 0.1 and 1.0 per cent was more effective in inhibiting sporulation than the vapor from concentrated or 10.0 per cent lime-sulfur. The effect of lime-sulfur was apparently due to the hydrogen sulfide evolved.

Therapeutic Action of Spray Fungicides.—To determine if fungicides could reduce the injury from downy mildew apart from their effect in protecting the plants from infection and inhibiting sporulation, several

tests were made in which infected seedling plants were sprayed with test fungicides 24 hours after inoculation with onion mildew, placed overnight in moist chambers in order to give the fungicide a better chance to act, then returned to the greenhouse bench, and harvested after 10 to 36 days. Control uninoculated plants were similarly treated in most of the tests. Control sprayed plants were necessary in order, in the final interpretation, to separate the effect of the fungicide on the plant from its effect on the disease. The results of 13 tests are summarized in table 24. Each value in the table represents the average yield of 4 pots of greenhouse seedlings. Rosin lime-sulfur, bordeaux + sulfonated miscible oil, and malachite green were chosen for these tests because field and greenhouse tests had indicated they were among the best for protection and for the inhibition of sporulation. In these tests, rosin lime-sulfur decreased the yield of healthy plants by an average of 4 per cent, and increased the yield of infected plants by 10 per cent, or the calculated increase in the yield of diseased plants due to the therapeutic action of the fungicide was 14 per cent. Bordeaux + sulfonated miscible oil increased the yield of healthy plants by 18 per cent and increased the yield of infected plants by 24 per cent, or the calculated increase due to the therapeutic action of the fungicide was 6 per cent. Malachite green + sodium oleyl sulfate decreased the yield of healthy plants by 7 per cent (only 2 tests) and increased the yield of infected plants by 43 per cent, or the calculated increase due to the therapeutic action was 50 per cent. As the average yield of infected unsprayed plants was only 42 per cent of the yield of healthy unsprayed plants in these tests, the therapeutic action of these fungicides on diseased plants was far from sufficient to restore them to yield values shown by the healthy plants. It might be considered that the results reported here might be due to a direct eradicant action of the fungicide in killing the mycelium in the tissues, or in reducing the rate of growth of the fungus, but this was not borne out in tests in which these same materials were tested more specifically for these effects (table 15, and text p. 647). Sporulation injury was not a factor in these tests, because the plants were not incubated in moist chambers to induce sporulation.

FIELD TESTS OF SPRAY FUNGICIDES FOR ONION-MILDEW CONTROL

Field applications before 1938 were made with a knapsack sprayer unless otherwise mentioned. Those in 1938 and 1940 were made with a compressed-air sprayer as manufactured for paint application, and powered with a small gasoline engine. Principally because the spray mechanism can be cleaned more easily, but also because it can be used

TABLE 24
**EFFECT OF FUNGICIDES ON THE GREEN WEIGHT OF HEALTHY AND DOWNY-MILDEW-
 INOCULATED GREENHOUSE ONIONS**

Date of test, period from spraying to harvest, and condition of plants	Green weight of tops, per pot			
	Not sprayed	Sprayed with 2 per cent rosin lime-sulfur	Sprayed with 1 per cent bordeaux + 0.5 per cent sulfonated miscible oil	Sprayed with 0.2 per cent malachite green + 0.1 per cent sodium oleyl sulfate
	grams	grams	grams	grams
January 20, 1937, harvested 10 days after spraying:				
Healthy	7.84	6.62	....	....
Inoculated.....	3.39	3.32	....	....
January 29, 1937, harvested 23 days after spraying:				
Inoculated.....	2.36	2.96	....	....
February 25, 1937, harvested 28 days after spraying:				
Inoculated.....	6.30	6.20	....	....
March 5, 1937, harvested 27 days after spraying:				
Healthy.....	6.93	5.95	5.25	....
January 5, 1938, harvested 32 days after spraying:				
Healthy.....	11.13	9.93	12.97	....
Inoculated.....	4.73	5.92	4.82	....
January 8, 1938, harvested 30 days after spraying:				
Healthy.....	5.53	6.67	5.66	....
Inoculated.....	2.91	2.33	2.98	....
January 14, 1938, harvested 33 days after spraying:				
Healthy.....	4.71	4.38	5.48	....
Inoculated.....	1.91	2.85	2.97	....
January 22, 1938, harvested 37 days after spraying:				
Healthy	4.45	4.23	4.71	....
Inoculated.....	1.78	1.86	2.81	....
February 5, 1938, harvested 35 days after spraying:				
Healthy.....	5.73	5.33	6.90	....
Inoculated.....	2.82	1.94	2.98	....
February 28, 1938, harvested 36 days after spraying:				
Healthy.....	8.45	7.89	....	6.43
Inoculated.....	2.47	2.62	....	3.78
March 4, 1938, harvested 30 days after spraying:				
Healthy.....	2.24	2.35	2.07	2.47
Inoculated.....	0.95	1.28	1.13	1.75
April 10, 1938, harvested 36 days after spraying:				
Inoculated.....	4.14	4.84	....	4.78
April 28, 1938, harvested 35 days after spraying:				
Inoculated.....	4.49	....	....	5.39

for vapor dusting with concentrated spray mixtures, the paint-gun equipment is considered much superior to the knapsack equipment. The engine and compressor for the paint-gun sprayer were mounted on a wheelbarrow, and the compressor was operated at 60 pounds air pressure. Spraying with either type of equipment was done thoroughly by spraying the plants first from one side of the row and then from the other. Onion rows in seed crops were about 36 inches apart, and there was some drift from a sprayed row to the adjacent row. Only alternate rows were treated in some of the 1935, 1936, and 1937 tests but as the drift of spray appeared of little importance, no buffer rows were left in the 1938 and 1940 plots. Except for the 1938 treatments on Early Grano at Milpitas, the replications of the same treatment were randomized throughout the area of treatment. Spraying was usually done in the early morning when there was little wind.

1935 Cotati Plots.—In the first field test, 4 per cent rosin soap, 0.25 per cent cuprous oxide + 2 per cent rosin soap, 1 per cent bordeaux, and 1 per cent of a miscible pine oil containing 20 per cent copper resinate were applied on March 27, April 3, 10, 18, 24, May 1, 8, 15, to single rows of White Portugal onions. At the time of first application, 22 per cent of the plants showed infection, and on April 17 all unsprayed plants showed infection. The first seedstalks were observed on April 3, and the first infection on seedstalks on April 17. The bordeaux mixture spread poorly on the leaves but the other sprays spread satisfactorily. Only the rosin soap and cuprous oxide + rosin soap showed marked protective properties. On May 8, seedstalk infection in the control plots was 50 per cent, in 1 plot sprayed with rosin soap 10 per cent, and in 1 plot sprayed with cuprous oxide + rosin 3 per cent. The plants sprayed with rosin soap only were pale in color and showed definite stunting apparently due to spray injury. On July 17, the number of seed-producing stalks in 50 feet of row for control, rosin soap, and cuprous oxide plots was 195, 198, and 269, respectively. On August 8, the ripe seed heads were harvested from 50 feet of row in each plot and the yield of cleaned seed for this picking was 119 grams (average of 3 plots) for the unsprayed control, 157 grams for the rosin-soap plot, and 373 grams for the cuprous oxide plot. No further yield records were secured because the remainder of the plots were harvested as a group by mistake. These 1935 preliminary results, however, indicated that partial control could be secured from frequent applications of cuprous oxide + rosin soap.

1936 Berkeley Plot.—A field planted with Yellow Bermuda bulbs—a highly susceptible variety—on July 31, 1935, was divided into one series of randomized plots each containing 5 plants per plot, and another series containing 25 plants per plot. Mildew infection was not

TABLE 25
FUNGICIDAL CONTROL OF ONION DOWNY MILDEW ON YELLOW BERMUDA ONIONS,
BERKELEY, 1936

Treatment	Plots	Plants infected April 25*	Seedstalks infected June 13		Yield of uncleaned seed per plot	
			Weekly† application	Fort-nightly† application	Weekly† application	Fort-nightly† application
	number	per cent	per cent	per cent	grams	grams
Series 1 (5 plants to each plot):						
Control, no treatment.....	10	86	..	84	....	7.0
2 per cent of a miscible pine oil containing 20 per cent copper resinate.....	2	50	11	27	81.4§	32.2§
2 per cent lime-sulfur + 0.2 per cent sodium oleyl sulfate.....	2	30	31	31	51.2	42.8
1 per cent cottonseed oil + 4 per cent rosin soap.....	2	10	24	42	37.1	39.0
2 per cent basic copper sulfate + 2 per cent rosin soap.....	2	0	42	62	20.6	52.5
1 per cent saponified copper resinate.....	2	30	45	63	5.5	60.9
4 per cent rosin soap.....	2	10	67	86	6.7	0.0
16 per cent rosin soap†.....	2	10	65	63	0.0	26.6
0.25 per cent cuprous oxide + 2 per cent rosin soap.....	4	25	71	64	16.5	15.4
1.0 per cent cuprous oxide + 2 per cent rosin soap.....	2	40	47	78	37.3	0.0
0.25 per cent copper sulfate + 4 per cent rosin soap.....	2	10	80	86	18.0	14.3
1.0 per cent bordeaux + 0.5 per cent sulfonated miscible oil.....	2	20	83	92	3.8	2.6
Cuprous oxide dust.....	2	90	..||	..||	....||	....||
Basic copper sulfate dust.....	2	90	..||	..||	....||	....||
Series 2 (25 plants per plot):**						
Control, no treatment.....	2	..	..	84	....	32.5
2 per cent lime-sulfur + 0.2 per cent sodium oleyl sulfate.....	2	..	..	60	....	105.0
1 per cent bordeaux + 0.5 per cent sulfonated miscible oil.....	2	..	..	88	....	50.0
0.25 per cent cuprous oxide + 2 per cent rosin soap.....	2	..	..	77	....	60.0

* Data for weekly and fortnightly applications included.

† Sprayed October 25, November 7, 14, 21, 29, 1935; January 20, 28, February 4, 15, 25, March 3, 11, 21, April 4, 13, 24, May 4, 1936.

‡ Sprayed October 25, November 7, 21, 1935; January 20, February 4, 25, March 11, 29, April 4, 24, 1936.

§ An average of 56.8 grams per plot = 726 pounds per acre.

|| Severe injury to plants.

|| Treatment discontinued because of obvious lack of control.

** Sprayed November 21, 1935; January 20, February 4, 25, March 3, 21, April 4, 24, 1936.

found in the plots until February 15, 1936, and was not abundant until April 13. Spray applications were started on October 25, 1936, in the absence of mildew infection, and the applications were made with a large hand atomizer with a pint jar as a container. In addition to downy mildew, considerable infection with *Botrytis allii* appeared in the plant-

ing, which killed many seedstalks, but there appeared little difference in its severity on treated and untreated plots. The onion plants were not so vigorous as is commonly observed in commercial plantings, but downy mildew and spray injury appeared to be the principal causes of differences between plots. A summary of important results from these tests

TABLE 26

FUNGICIDAL CONTROL OF ONION DOWNY MILDEW ON GREEN ONIONS FOR BUNCHING,
BAY FARM ISLAND, 1936-37

Treatment	Leaves sporulating November 23		Green weight of plants in 2 feet of row, average per plot			
	Sprayed October 23, November 3, 12	Sprayed October 23, November 3	December 12, 1936		January 14, 1937	
			Sprayed October 23, November 3, 12, 23, 30	Sprayed October 23, November 3, 23	Sprayed October 23, November 3, 12, 23, 30, December 12, 21, 31	Sprayed October 23, November 3, 23, December 21
	per cent	per cent	grams	grams	grams	grams
Series 1 (4 plots of each):						
Control, no treatment.....	81	..	170	...	234	...
1 per cent bordeaux + 0.5 per cent sulfonated miscible oil ..	10	66	235	181	258	297
2 per cent lime-sulfur + 0.2 per cent sodium oleyl sulfate.....	51	84	184	201	308	291
Rosin soap + 2 per cent lime- sulfur*.....	1	49	270	287	384†	367
Series 2 (2 plots of each):						
2 per cent miscible pine oil con- taining 20 per cent copper resinate.....	0	54	163	217	...	...
1 per cent rosin soap + 1 per cent cottonseed oil.....	5	70	153	126	...	...
1 per cent rosin soap + 0.5 per cent lime-sulfur.....	71	83	209	183	...	...

* In two plots 2 per cent rosin soap was used, in two others 4 per cent. Heavier deposit, better disease control, and more host injury resulted from the use of 4 per cent rosin soap.

† 384 grams per 2 feet of row = about 20,800 pounds per acre.

is given in table 25. The plots were obviously too small for material so variable, and downy mildew was less severe and destructive than on plants of this variety at Milpitas in 1938 and 1940, but the results indicate marked disease control with several sprays, including copper resinate in pine oil and lime-sulfur.

1936-37 Bay Farm Island Plot.—On October 23, 1936, a field of onions grown for bunching on Bay Farm Island showed about 25 per cent of the plants with mildew sporulation. The plants were growing in rows 8 inches apart with an average of 32 plants per linear foot of row. A total of 22 plots, 14 of them consisting of 2 parallel rows 4 feet long and 8 of them consisting of 2 rows 33 feet long, were laid out in a uniform

portion of the planting and sprayed as indicated in table 26. Very little apparent development of the disease occurred between October 23 and November 12, but on November 23, every untreated plant examined showed sporulation. All plants sprayed October 23 and November 3 and 12 showed much less sporulation than the controls, but on plots where the

TABLE 27

EFFECT OF TIME AND FREQUENCY OF APPLICATION OF 2 PER CENT ROSIN LIME-SULFUR FOR ONION-MILDEW CONTROL ON AUSTRALIAN BROWN ONIONS, MILPITAS, 1937
(20 feet of row per plot)

Dates of spray application	Plots	Seedstalks healthy		Cleaned seed per plot
		May 28	August 13	
	number	per cent	per cent	grams
Control, untreated.....	10	43	9	326 (average of 4 plots)
1 application:				
April 23.....	1	78	8	.....
April 30.....	1	40	10	.....
May 7.....	1	47	4	.....
May 14.....	1	49	19	.....
May 21.....	1	38	8	.....
May 28.....	1	37	20	.....
Total or average for 1 application.....	6	48	11	.....
2 applications:				
April 23, May 7.....	1	93	35	.....
April 23, May 21.....	1	92	22	.....
April 30, May 14.....	1	44	7	.....
April 30, May 28.....	1	54	20	.....
May 7, 21.....	1	68	29	.....
May 14, 28.....	1	53	38	.....
Total or average for 2 applications.....	6	67	25	.....
3 applications:				
April 23, May 7, 21.....	5	68	46	562 (average of 4 plots)
April 30, May 14, 28.....	1	57	49	.....
Total or average for 3 applications.....	6	62	47	.....
6 applications:				
April 24, 30, May 7, 14, 21, 28.....	4	94	65	723* (average of 4 plots)

* 723 grams per plot = 1,158 pounds of seed per acre.

November 12 application was omitted, sporulation was relatively abundant. One sample harvest was made on December 12, 1936, and another on January 14, 1937. The results presented in table 26 show a marked increase in yield from most treatments with the greatest increase from rosin lime-sulfur.

1937 Milpitas Plot.—The 1937 treatments were divided into two groups, one to determine the optimum time and frequency of application and one to compare different materials. In the test of time and frequency of application, rosin lime-sulfur was applied in single applications and

in various combinations of 2 to 6 applications. The results, presented in table 27, indicate no markedly significant optimum time of application though the single May 14 and May 28 applications appear superior

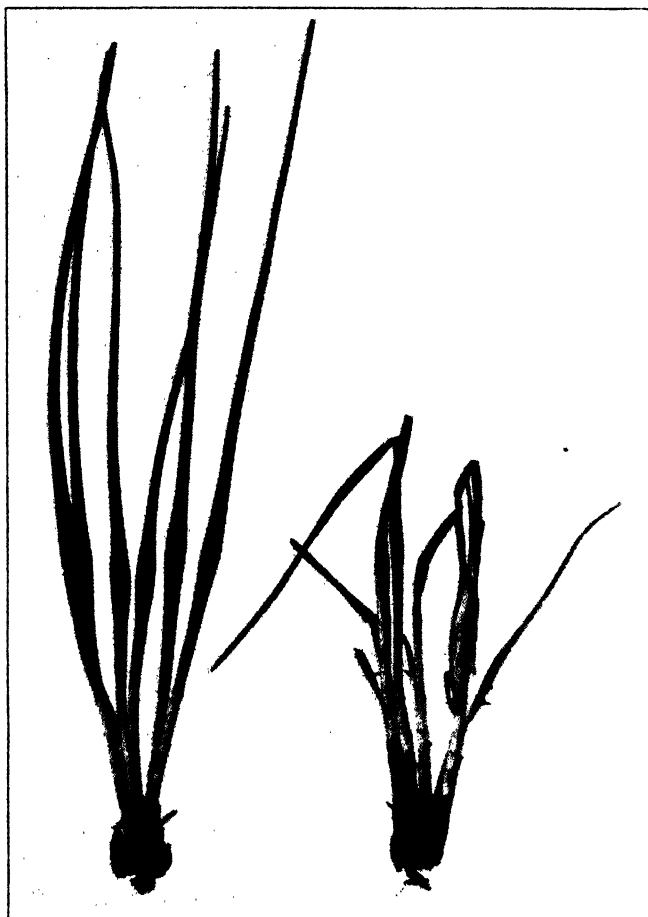


Fig. 12.—Effect of spraying on the control of onion downy mildew and *Macrosporium* on Australian Brown onions. Plant on left from plot sprayed April 24, 30, May 7, 14, 21, 28 with 2 per cent rosin lime-sulfur. Plant on right from unsprayed plot. Photographed August 13, 1937, just after seed heads had been harvested.

to the earlier single applications. Increased frequency of application greatly increased the number of healthy seedstalks, the values being 9 per cent healthy seedstalks with no applications, 11 per cent with 1 application, 25 per cent with 2 applications, 47 per cent with 3 applications, and 65 per cent with 6 applications. Yield records show the same trend,

increasing from 326 grams per plot with no applications to 562 grams with 3 applications, and 723 grams with 6 applications. A plant from a control plot and one from a plot receiving 6 applications of spray are illustrated in figure 12.

In the comparison of materials, all treatments showed marked increases in yield over the untreated plots, and the bordeaux + sulfonated miscible oil and rosin lime-sulfur produced the greatest increases in yield (table 28).

TABLE 28

FUNGICIDAL CONTROL OF ONION DOWNY MILDEW ON AUSTRALIAN BROWN ONIONS, MILPITAS, 1937

(10 feet of row per plot; applications April 24, May 7, and 21)

Spray treatment	Seedstalks healthy		Cleaned seed per plot*
	June 4	August 13	
	per cent	per cent	grams
Control, no treatment.....	34	4	113, 113, 113, 85
2 per cent lime-sulfur + 0.1 per cent sodium oleyl sulfate...	51	21	198, 226, 142
1 per cent bordeaux + 0.5 per cent sulfonated miscible oil..	60	58	198, 198, 397†
2 per cent rosin lime-sulfur.....	73	47	312, 312, 142‡
2 per cent miscible pine oil containing 20 per cent copper resinate.....	63	42	142, 227, 170

* These yields were originally recorded to the nearest ounce. This accounts for the apparent identity of several plot yields.

† An average of 264 grams per plot = 847 pounds per acre.

‡ The April 24 application was omitted on this plot.

1938 Milpitas Plot.—The 1938 treatments on Yellow Bermuda were designed to test the effect of frequency of application, to compare materials, and to compare the use of concentrated sprays (vapor dusting or fog spraying) with the use of the more conventional dilute sprays. An attempt was made to apply about the same amount of active ingredients in the light fog applications as in the applications of dilute sprays, and the heavy fog application was about twice as heavy as the light. The results, presented in table 29, indicate that marked control of downy mildew and increase in seed yield resulted from most of the treatments, the best being weekly applications of dilute rosin lime-sulfur spray. A treated and control plot are illustrated in figure 13.

The yield of plants sprayed weekly with rosin lime-sulfur was 58 times that of the control plants. In spite of the data of table 29 it is not safe to conclude that the light applications of concentrated sprays are inferior to the heavy wash applications of dilute sprays. The equipment and arrangement of test plots was not ideal for such a comparison, and a more efficient applicator and larger plots would have been desirable for fog applications.

TABLE 29
FUNGICIDAL CONTROL OF ONION DOWNY MILDEW ON YELLOW BERMUDA ONIONS,
MILPITAS, 1938
(10 feet of row per plot)

Treatment	Seed-stalks infected May 24	Erect seedstalks per plot		Yield of clean seed	
		April 27	July 7	Yield of each plot	Average for treatment
	<i>per cent</i>	<i>number</i>	<i>number</i>	<i>grams</i>	<i>grams</i>
Control, no treatment.....	59	68	43	1.78, 2.47, 0, 0.56, 2.18, 1.53, 1.66, 1.61, 3.75	1.73
2 per cent rosin lime-sulfur spray:					
Weekly*.....	25	90	52	52.2†, 129.2, 98.5, 122.7	100.7‡
Fortnightly§.....	29	88	35	82.6, 8.47, 45.2, 20.4	39.2
10 per cent rosin lime-sulfur fog, light:					
Weekly*.....	36	82	27	3.25, 120.9, 3.60, 26.4	38.5
Fortnightly§.....	50	78	11	9.93, 3.12, 5.40, 9.87	7.08
10 per cent rosin lime-sulfur fog, heavy:					
Weekly*.....	38	64	13	11.5, 3.22, 75.5, 6.34	24.1
Fortnightly§.....	45	82	14	10.9, 5.27, 4.54, 23.0	10.9
0.25 per cent cuprous oxide + 0.25 per cent cottonseed-oil-emulsion spray:					
Weekly*.....	19	96	35	24.4, 93.8, 20.6	46.2
Fortnightly§.....	29	66	8	7.55, 1.09	4.32
2.5 per cent cuprous oxide + 2.5 per cent cottonseed-oil-emulsion fog:					
Weekly*.....	39	71	14	10.6, 1.78, 15.5	9.29
Fortnightly§.....	43	66	7	0.40, 7.78	4.09
0.2 per cent malachite green + 0.2 per cent sodium oleyl sulfate:					
Weekly*.....	20	91	29	69.9, 8.03	39.0
Fortnightly§.....	45	78	15	10.5, 8.09	9.29
0.25 per cent tetramethyl thiuram disulfide:					
Weekly*.....	49	102	10	10.5, 7.50	9.00
Fortnightly§.....	62	105	6	3.34, 3.22	3.28

* Sprayed February 25, March 4, 14, 21, 30, April 6, 13, 20, 27, May 6, 16, 23.

† Several plants were injured by cultivation.

‡ 100.7 grams per plot = 322 pounds per acre.

§ Sprayed February 25, March 14, 30, April 13, 27, May 16.

The 1938 Milpitas plot on Early Grano was designed to compare rosin lime-sulfur with bordeaux and cottonseed oil and to compare spray with fog applications. The area under test consisted of 6 rows 200 feet long. The stand was poor, many of the bulbs having rotted during the winter, but was fairly uniform. The area was divided into 3 sections 67 feet in length, and the 6 rows of the center section were left as a control. At one end of the area, 3 rows were treated with rosin lime-sulfur spray and 3

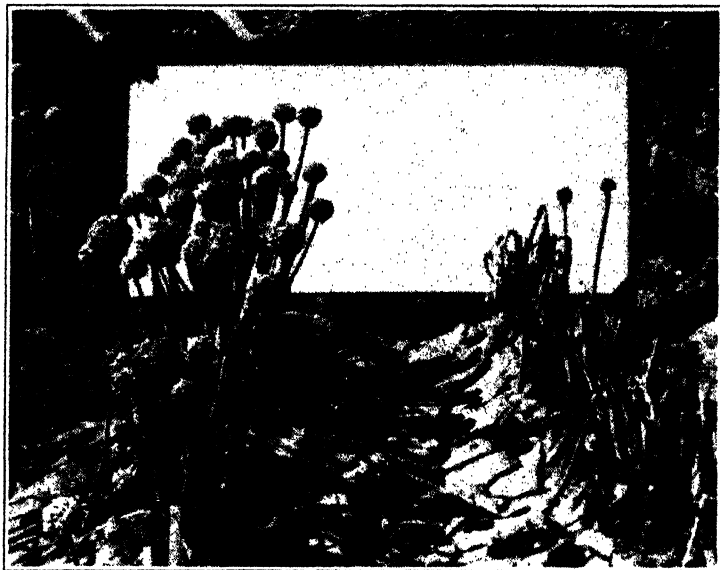


Fig. 13.—Fungicidal control of onion downy mildew on Yellow Bermuda onions at Milpitas, 1938. Plot on left was sprayed February 25, March 4, 14, 21, 30, April 6, 13, 20, 27, May 6, 16, 23 with 2 per cent rosin lime-sulfur. Plot on right was unsprayed.

TABLE 30

FUNGICIDAL CONTROL OF ONION DOWNY MILDEW ON EARLY GRANO ONIONS,
MILPITAS, 1938

(Plots 67 feet long, not randomized; poor stand of plants)

Treatment	Plots	Average yield per plot	
		Heads harvested	Cleaned seed harvested
	number	number	grams
Control:			
0 applications.....	6	135	133
2 per cent rosin lime-sulfur spray:			
5 applications*.....	2	172	194
4 applications†.....	1	147	275
10 per cent rosin lime-sulfur fog:			
5 applications*.....	2	129	110
4 applications†.....	1	197	163
0.5 per cent bordeaux + 0.5 per cent cottonseed-oil spray:			
5 applications*.....	2	151	256
4 applications†.....	1	88	124
5.0 per cent bordeaux + 5.0 per cent cottonseed-oil fog:			
5 applications*.....	2	142	299‡
4 applications†.....	1	140	200

* Applications March 30, April 6, 20, May 6, 23.

† Applications March 30, April 6, 20, May 6.

‡ 299 grams per plot = 142 pounds per acre.

with rosin lime-sulfur fog; at the other end, 3 rows were treated with bordeaux cottonseed-oil spray and 3 with bordeaux cottonseed-oil fog. Downy mildew was only moderately severe, and *Botrytis allii* was moderately abundant, but infection was not counted. The results presented in

TABLE 31
FUNGICIDAL CONTROL OF ONION DOWNY MILDEW ON YELLOW BERMUDA ONIONS,
MILPITAS, 1940
(10 feet of row per plot)

Treatment	Plots	Average erect seedstalks, per plot		Yield of cleaned seed per plot	
		May 10	July 15	Yield of each plot	Average for treatment
	number	number	number	grams	grams
Control:					
0 applications	10	19.6	1.0	0.40, 0.11, 0.08, 0.66, 0.01, 0.13, 1.43, 0.0, 0.0, 0.05	0.29
2 per cent rosin lime-sulfur:					
Weekly*	5	46.2	9.2	6.30, 19.5, 1.87, 8.76, 3.20	7.92†
Fortnightly‡	5	34.4	8.2	1.33, 0.30, 1.54, 3.94, 2.29	1.88
0.2 per cent cuprous oxide + 0.2 per cent self-emulsi- fying cottonseed oil:					
Weekly*	5	26.4	2.4	0.28, 0.02, 1.60, 0.25, 0.67	0.56
Fortnightly‡	5	20.4	3.6	0.62, 6.33, 0.01, 1.10, 1.20	1.85
0.2 per cent cuprous oxide + 0.2 per cent self-emulsi- fying cottonseed oil + 0.2 per cent malachite green:					
Weekly*	5	29.0	3.2	1.79, 3.20, 2.28, 1.58, 0.89	1.95
Fortnightly‡	5	29.0	3.8	0.85, 2.57, 0.17, 0.32, 0.20	0.82
0.5 per cent bordeaux + 0.5 per cent cottonseed oil:					
Weekly*	5	18.8	4.0	2.02, 0.14, 6.91, 0.0, 0.57	1.93
Fortnightly‡	5	16.0	2.6	0.0, 0.65, 1.40, 1.90, 0.22	0.83

* Sprayed March 4, 11, 18, 25, April 1, 8, 15, 22, 29, May 6, 13.

† 7.92 grams per plot = 89 pounds per acre.

‡ Sprayed March 4, 18, April 1, 15, 29, May 13.

table 30, show rather erratic results but indicate a marked increase in yield from most treatments, with the greatest increase in yield from bordeaux cottonseed-oil fog.

1940 Milpitas Plot.—The 1940 Milpitas plot was designed mainly as repetition of previous tests, but more plots of each treatment were used in order to increase the significance of yield differences. Applications were started on March 4, too late for good control because leaf infection was already severe and many seedstalks were already infected. The results summarized in table 31 indicated a marked increase in yield from all treatments, and rosin lime-sulfur spray weekly appeared to be the best treatment.

MISCELLANEOUS OBSERVATIONS ON FIELD TESTS WITH FUNGICIDES

The amount of spray required for onions varies with the size of plants, spacing of rows, wind, spreading properties of spray, and the type of equipment used, and is more than one might expect from the small size and convenient exposure of the leaves and seedstalks. For Yellow Bermuda onions with fully extended seedstalks, about 1 liter of rosin lime-sulfur spray was required per 10 feet of row, or about 320 gallons per acre under the conditions of the experimental tests.

Most sprays caused injury to onions under field conditions, but 2 per cent lime-sulfur + 0.1 per cent sodium oleyl sulfate appeared to be slightly stimulatory to healthy bulb plants at Concord and healthy seed plants at Cotati in 1936. Rosin lime-sulfur caused marked injury to Yellow Bermuda onions, which injury was manifest as a scorching of the seedstalks. But in spite of this spray injury, applications of rosin lime-sulfur caused marked reduction in downy-mildew infection and increase in yield when applied under conditions of heavy infection. Bordeaux mixture seemed to cause a general weakening of Yellow Bermuda plants but no localized injury was observed. Australian Brown onions showed no apparent injury from any sprays tested.

During 1938, 1939, and 1940, a commercial grower sprayed several lots of onions at Milpitas. In 1938 and 1940, 2 per cent rosin lime-sulfur was used, and 0.5 per cent bordeaux + 0.5 per cent cottonseed oil was used in 1939. Though unsprayed controls were not maintained for comparison, mildew control did not appear highly satisfactory, and considerable disease developed in the sprayed plants. In 1939 most of the disease injury was apparently due to *Botrytis allii*. These commercial applications of rosin lime-sulfur and bordeaux + cottonseed oil with high impact pressures, appeared to cause more severe injury to onions than the experimental applications with low impact pressures.

None of the spray treatments was effective in preserving the leaves of plants grown for seed. In all cases of severe infection the leaves were usually killed by blossoming time, though they usually persisted longer on sprayed than on unsprayed plants.

DISCUSSION OF FUNGICIDAL CONTROL OF ONION MILDEW

The results of all successful field tests for onion-mildew control, given in some detail in tables 25 to 31, and summarized briefly in table 32, demonstrate that with a severe infection, plants sprayed frequently with a suitable fungicide will greatly outyield unsprayed plants. Complete or nearly complete control, however, was not secured in any test. The high

incidence of infection was most likely due in part to the severe conditions of these tests. In all cases many unsprayed control plots were maintained, and as these were heavily infected in the successful tests (those in which a high incidence of disease occurred and marked yield increases from spraying resulted), the sprayed plants were subjected to continuous and heavy inoculation. In addition to the untreated controls, many of the treatments were not expected to and did not give as satisfactory

TABLE 32

SUMMARY OF BEST TREATMENTS USED IN FIELD TESTS FOR FUNGICIDAL CONTROL OF ONION DOWNY MILDEW

Date of first spray application, location, and type of crop	Condition of mildew at start of test	Best treatment used			Yield of best treatment as a percentage of yield of unsprayed control plots
		Spray material	Successive applications of same spray	Replications of treatment	
			number	number	per cent
March 27, 1935, Cotati, for seed	Abundant	Cuprous oxide + rosin soap	8	1	315
October 25, 1935, Berkeley, for seed	Absent	Copper resinate in pine oil	19	2	797
October 23, 1936, Bay Farm, for greens	Abundant	Rosin lime-sulfur	8	4	160
April 23, 1937, Milpitas, for seed	Abundant	Rosin lime-sulfur	6	4	222
February 25, 1938, Milpitas, for seed	Abundant	Rosin lime-sulfur	12	4	5,820
March 30, 1938, Milpitas, for seed	Moderate	Bordeaux + cottonseed oil	5	2	224
April 29, 1938, Sacramento, for seed	Moderate	Bordeaux + cottonseed oil	4	2	No record
March 4, 1940, Milpitas, for seed	Abundant	Rosin lime-sulfur	11	5	2,730

control as others, and the plots showing poor control also were presumably partly responsible for a heavy spore shower on the sprayed plants. Furthermore, in all successful tests but the 1936 Berkeley test and the March 30, 1938, Milpitas test, the experimental block of onions was immediately adjacent to, or only a few feet distant from, a block of unsprayed mildew-susceptible and heavily infected onions.

In addition to 8 successful tests (table 32) in which mildew infection was severe and significant increases in yield due to spray treatment were noted, 5 tests were performed in which practically no increase in mildew occurred after the tests were started. In the test of January 15, 1936, at Concord, healthy plants grown for bulbs were sprayed in duplicate plots with cuprous oxide + rosin soap, bordeaux mixture + spreader, lime-sulfur + sodium oleyl sulfate, rosin soap, copper resinate soap, and precipitated copper resinate on January 15, 30, February 15, and March

3, 17, 31. On March 31 no mildew infection had appeared in the planting and the test was discontinued. The 1 per cent bordeaux mixture + spreader caused slight injury, but the other treatments showed no injury, and plots sprayed with 2 per cent lime-sulfur + 0.2 per cent sodium oleyl sulfate appeared slightly more vigorous than the other treated plots or the untreated controls. In the test of January 22, 1936, at Cotati, plants grown for seed were sprayed with the same materials and at approximately the same time as the January 15, 1936, plot at Concord. This test was discontinued on March 4 because only a trace of mildew had appeared in the planting. In the test of March 19, 1936, at Concord, onions grown for seed and showing moderate infection were sprayed in triplicate plots with bordeaux mixture + spreader and cuprous oxide + rosin soap on March 19, 31, April 10, 21, and May 4. The treatments were discontinued on May 4 and no further records were taken because mildew had apparently not increased since the start of the test. The other unsuccessful tests, one at Sacramento, and one at Concord, were also discontinued because mildew failed to become abundant in the untreated plots during the late spring or early summer months.

Although this report involves several successful field tests of fungicides, the results do not constitute an adequate basis for recommendations for the commercial control of onion mildew with fungicides. The most successful field tests were at Milpitas, where onion mildew appeared earlier, and did more damage than at Cotati, in the Sacramento-San-Joaquin Delta region, or in the southern part of the Santa Clara Valley, each of which districts is more characteristic of onion culture in California than Milpitas. A less intensive onion-mildew-control program would very likely be required in these other districts than was necessary at Milpitas.

All sprays were applied with rather miniature equipment in this study, and the problem of proper equipment for applying fungicides to onions was not studied. Equipment built high enough to clear the tops of onion seedstalks would probably be necessary.

So far as this study would indicate, dusting would not give control, and conventional dilute sprays would be most successful, but vapor dusting with ground or air-borne equipment would seem very promising. Several fungicidal sprays gave marked protection against onion mildew and marked increases in yield of onion seed, but which material was best, however, is not obvious. Applications of rosin lime-sulfur were associated with the two highest relative yields in this study, but it was also more thoroughly tested than any other material. Advantages of rosin lime-sulfur over some of the other sprays used are its low cost and its

convenience of preparation if the stock materials are available. Disadvantages of rosin lime-sulfur are the labor of preparing the rosin soap and the tendency of the spray to form gum. Because of the high viscosity of rosin lime-sulfur, preparations containing 10 per cent of each of the liquid components in water are about the maximum concentration which will maintain satisfactory liquid properties, and this difficulty of getting a concentrated spray would probably make the use of rosin lime-sulfur impractical as a commercial fog spray. Bordeaux mixture with cottonseed oil was a promising combination but this has the disadvantage of requiring 4 components, and if the copper sulfate and lime must be prepared as separate stock solutions, the labor of preparation becomes considerable. The bordeaux + cottonseed-oil combination was unsatisfactory on Yellow Bermuda in 1940. Copper resinate in pine oil appeared to be the best material tested in the 1935-36 plot at Berkeley, but in the 1937 plot at Milpitas it was the poorest. This is possibly because the materials used in those two seasons were from different samples with quite different physical properties.

GENERAL DISCUSSION OF ONION-MILDEW CONTROL

The methods that appear most promising for offsetting the danger from onion mildew are: the development of mildew-resistant varieties, the avoidance of disease, the production and storage of sufficient seed in seasons when the disease is not severe to make up for losses during seasons of mildew severity, and the use of protective sprays. The production of mildew-resistant onions has already been discussed.

Avoidance of the disease might be accomplished by several methods. First, only healthy bulbs should be used as planting stock. If bulbs suspected of harboring the disease are to be used, the infection should be killed out by heat treatment. The bulbs should be planted some distance from other onion fields, and contaminated soil or refuse should be avoided. Second, onions should be grown if possible in a location unfavorable for the development of onion mildew. While in general, districts favorable for onion-seed production appear favorable for the development of onion mildew, some, because of local freedom from dew or rain at critical periods may be unfavorable for its development. When one considers that enough onion seed for the United States for one year can be produced by 1,000 to 2,000 acres of healthy high-yielding onions, the problem of avoiding the disease should not be unsurmountable.

The production of sufficient onion seed in seasons when onion mildew is not severe, to make up for losses in mildew-severe seasons is one of the principal methods in practice for meeting the losses from onion mildew. With improved knowledge of optimum storage conditions for onion

seed (4), this method might be used with more certainty, but to the individual grower the method involves the risk of loss of a large part of his crop in epidemic seasons.

Protective sprays should be used to supplement the above-discussed control methods. According to the observations and results reported in this study, it would appear inadvisable to apply protective fungicides before the disease is actually present in an onion planting. In several tests reported here, marked control was secured by spraying started after the disease was well established. The critical period for protection appears to be during growth of the seedstalks. If infection has become established before the seedstalks emerge, many applications might be necessary to secure adequate control, but if infection did not become established until the seedstalks had completed their elongation, one application might be sufficient. In this study, spraying dates were arbitrarily chosen about a week apart irrespective of the development of the disease, because frequent observation of the plantings was impractical. In practice, however, it would appear desirable to time the sprays according to the observed development of the disease. Sporulation under field conditions is rather erratic, and spray coverage during periods when no sporulation occurred would be of much less value than sprays applied preceding and following active sporulation.

SUMMARY

Onion mildew was first reported in England in 1841, and is now world-wide in distribution. The disease is most severe on the seed crop, and losses of from 0 to 70 per cent of the California onion seed crop due to onion-mildew infection have been reported. Losses in individual fields vary from none to complete. The leaves, which are usually infected first, are apparently of little importance to the seed crop, but when the seedstalks are infected the yield is reduced.

Onion mildew has been recorded on the following species of onions: *Allium Cepa*, *A. fistulosum*, *A. nigrum*, *A. Porrum*, *A. ursinum*, *A. oleraceum*, *A. sativum*, *A. ascalonicum*, and *A. Schoenoprasum*. Only *A. Cepa* and *A. fistulosum* have been observed infected in this study. All varieties of the common onion are susceptible, but marked differences exist between varieties in the amount of injury caused by mildew infection.

Characteristic symptoms are the paling, down-curling, and narrowing of the leaves in systemic infections, the large, oval, slightly chlorotic lesions on leaves and seedstalks resulting from secondary infection, and a general killing of the leaf tips. The grayish-violet downy growth of sporangiophores on the surface of infected tissues is the most characteristic sign of the disease.

Peronospora destructor Berk. appears to be the proper name of the organism causing onion downy mildew. A description of the organism and a discussion of its nomenclature is given. Sporangia of *P. destructor* have failed to make continued growth on agar media to which various test nutrients were added. The most stimulatory of the test nutrients was potassium permanganate, dibasic sodium phosphate, glycine, and melted agar cultures of *Phytophthora citrophthora*. Host extracts were toxic in heavy doses and slightly stimulatory in small amounts. On agar plates the germ tubes grew at about 30μ per hour.

Other organisms causing important losses to onions observed in this study were, in order of importance: *Botrytis allii*, *Macrosporium*, and *Botrytis cinerea*. All were less important than *Peronospora destructor*. *Macrosporium* infection was more frequent on the north side than on the south side of onion seedstalks.

In California the principal method by which onion mildew is carried over from one season to another is believed to be by means of mycelium in the bulbs. The amount of seasonal carryover is small. Seed from heavily infected plants produced healthy plants in 2 tests.

Sporangia are normally formed at night, matured in the early morning, and liberated throughout the day. The optimum relative humidity for the formation of sporangia was about 100 per cent and the minimum about 90 per cent. Sporulation in low relative humidity caused the sporangiophores to be shorter than at high humidity. The formation of sporangiophores is governed by the alternation of light and darkness in the normal day as well as the relative humidity. The formation of sporangiophores and sporangia causes injury to the infected plants. Sporangia are disseminated by wind.

When attached to sporangiophores on living leaves sporangia remain viable for about 3 days, but when detached and on the surface of healthy leaves sporangia remain viable for only about 1 day.

Germination of sporangia occurs in the presence of free water, and the germ tube enters the host through the stomata by means of an appressorium and a substomatal vesicle. In the process of penetration of onion mildew, nuclei of the adjacent onion epidermal cells move toward the invaded stomata. Germ tubes had penetrated beyond the killing action of drying or eradicant sprays in about 7 hours, and the mycelium grew at the rate of about 300μ per hour in the leaf. Infected tissues sporulated in a minimum of 5 days after inoculation in one test, but this interval was usually longer.

Artificial inoculation was successfully accomplished by a variety of methods. Systemic infection of plants grown from bulbs was induced by injecting a spore suspension into the bulbs before planting them.

The epidemiological factors considered of most importance in determining the severity of onion mildew attacks are inoculum, temperature, moisture conditions, and wind. Onion mildew may be severe in the absence of rain.

Sporangia germinate better on plain agar than in water. Sporangia germinated and caused infection at temperatures from 1° to 28° C with an optimum at about 13° C. Sporangioophores were formed at temperatures from 7° to 22° C.

Downy-mildew mycelium was killed by heating infected bulbs for 4 hours at 41° C and by heating infected leaves for 10 hours at 37° C.

Onion leaves were less readily wetted by water than were other leaves tested, but were readily wetted by water or by water suspensions of fungicides to which certain spray supplements were added.

The action of spray fungicides on onion mildew was studied by several methods. In spore-germination tests, peptone and asparagine were antagonistic to bordeaux mixture. Sulfur dust was toxic to sporangia on agar plates and on rubbed onion leaves, but was not toxic on glass slides or on normal onion leaves. Sulfur sprays were more effective than copper sprays in inhibiting sporulation. Spraying infected plants with rosin lime-sulfur or with malachite green apparently did not kill the mycelium in the tissues but did reduce the injury from infection. The addition of vegetable oils to several copper sprays increased the protective value of these sprays. In all field tests in which onion mildew was severe in the untreated plots, spraying with various fungicides reduced the incidence of disease, and increased yields by 60 to 5,700 per cent in different tests. Rosin lime-sulfur was perhaps the best fungicide mixture tested. Applications of concentrated sprays in the form of vapor dusts gave marked control of onion mildew, but no control was secured with dry-dust fungicides.

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